Electromagnetic Final States in MINERvA

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NuFact 2012, July 23-28, 2012 Williamsburg, VA

Overview

- Motivation
- MINERvA detector
- CC $1\pi^0$ reconstruction
- e/γ Separation using dE/dx
- Michel electron for calibration check
- Single electron final states ($\nu_\mu + e^- \longrightarrow \nu_\mu + e^-$ and ν_e CCQE)

Motivation

- An understanding of electromagnetic final states is important for ν_e appearance experiment
- NC π^0 mimics ν_e CCQE (appearance signature) when one of photon is not detected
- ν_e CCQE in near detector measures ν_e beam contents, which is irreducible background to ν_e appearance
- $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ scattering measurement gives a constraint on beam flux

π^0 Final States

NC Resonant π^0

$$\nu_\mu + p \rightarrow \nu_\mu + p + \pi^0$$
$$\nu_\mu + n \rightarrow \nu_\mu + n + \pi^0$$

NC Coherent π^0

$$\nu_\mu + A \rightarrow \nu_\mu + \pi^0 + A$$
$$\bar{\nu}_\mu + A \rightarrow \bar{\nu}_\mu + \pi^0 + A$$

CC Resonant π^0

$$\nu_\mu + n \rightarrow \mu^- + p + \pi^0$$
$$\bar{\nu}_\mu + p \rightarrow \mu^+ + n + \pi^0$$

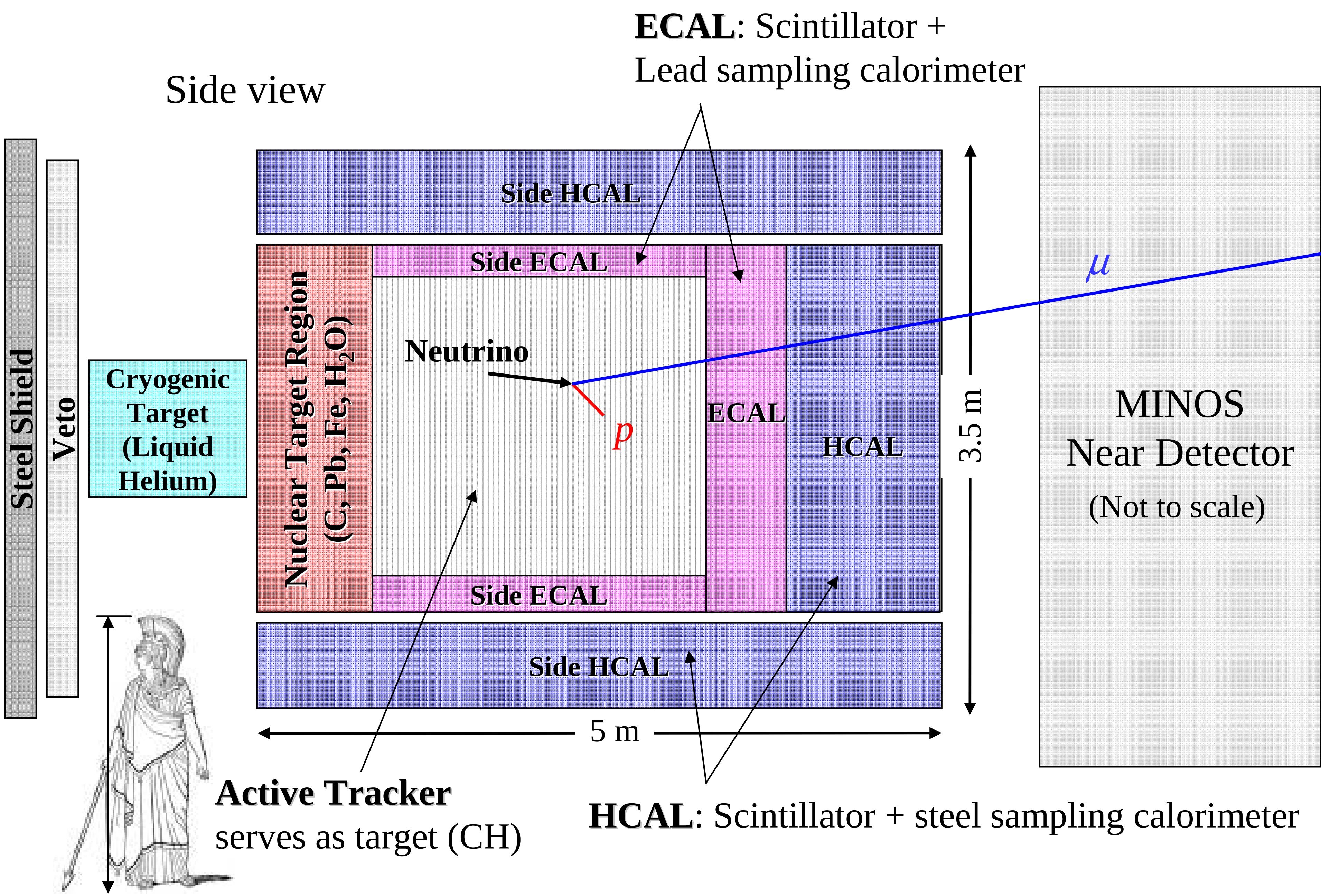
In terms of final states

NC	CC
π^0	$\mu^+ + \pi^0$
$\pi^0 + p$	$\mu^- + \pi^0 + p$

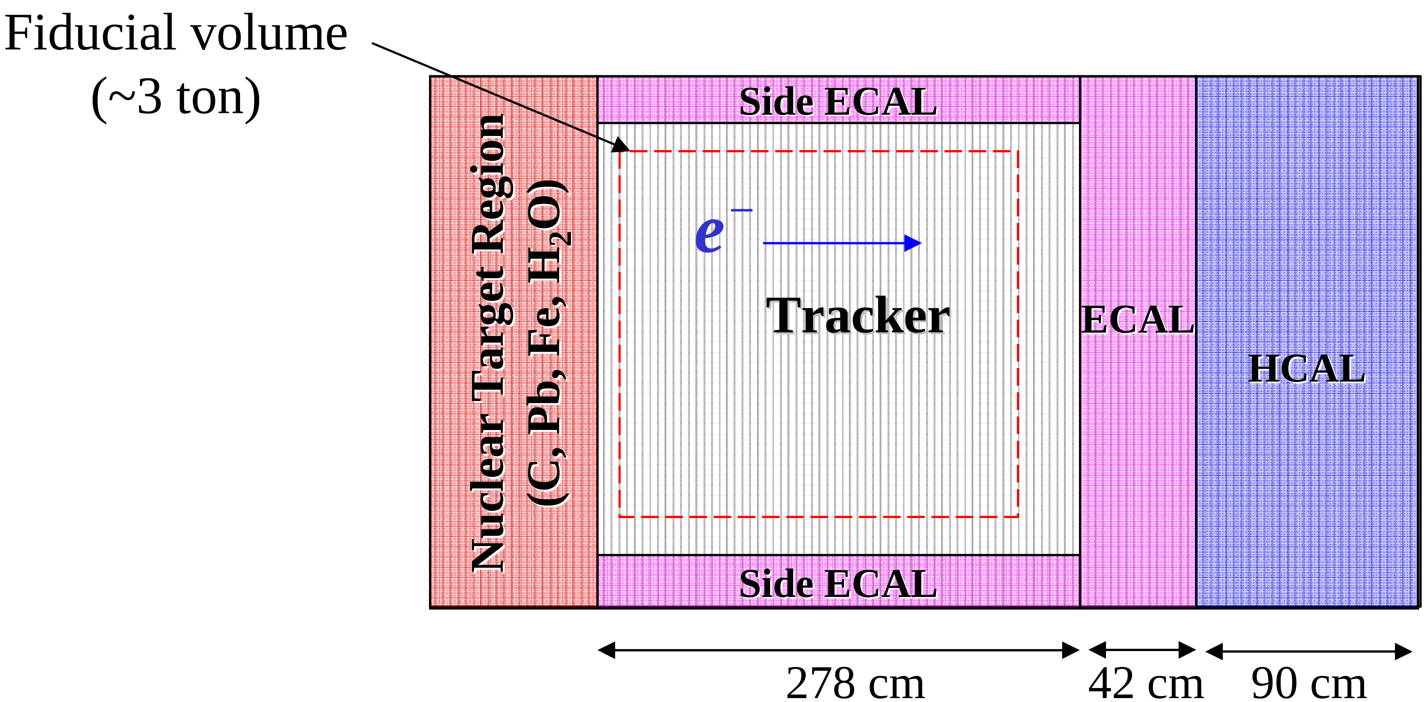
- NC π^0 is more interesting channel but more difficult than CC π^0
- CC π^0 reconstruction takes advantage of muon vertex
- Both NC and CC π^0 reconstruction study is ongoing but preliminary CC π^0 result is presented today
- CC π^0 is valuable for understanding of resonant pion production

MINERvA Detector

- MINERvA detector is made of a stack of “MODULES” (See next slide)



Calorimeter

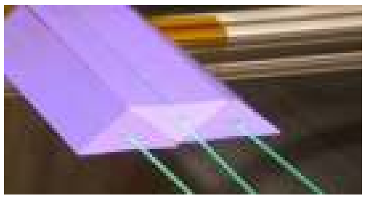


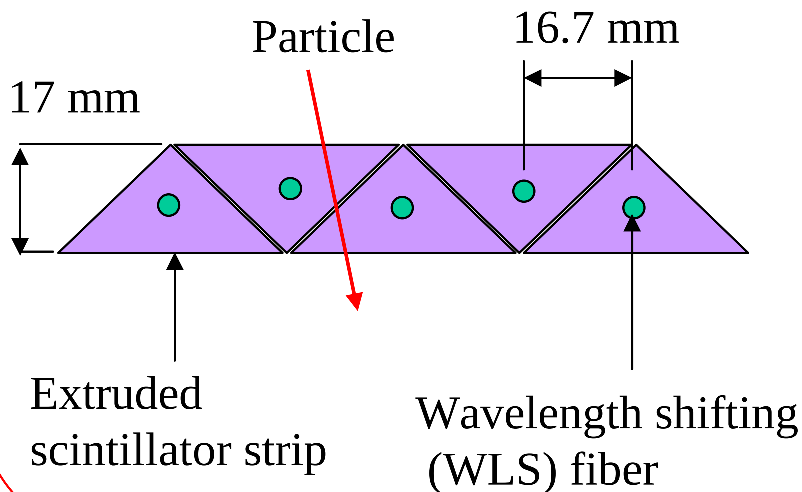
- Tracker: 1.7 cm scintillator plane
- Ecal: 2mm lead + 1.7 cm scintillator plane
- Hcal: 2.54 cm steel + 1.7cm scintillator plane

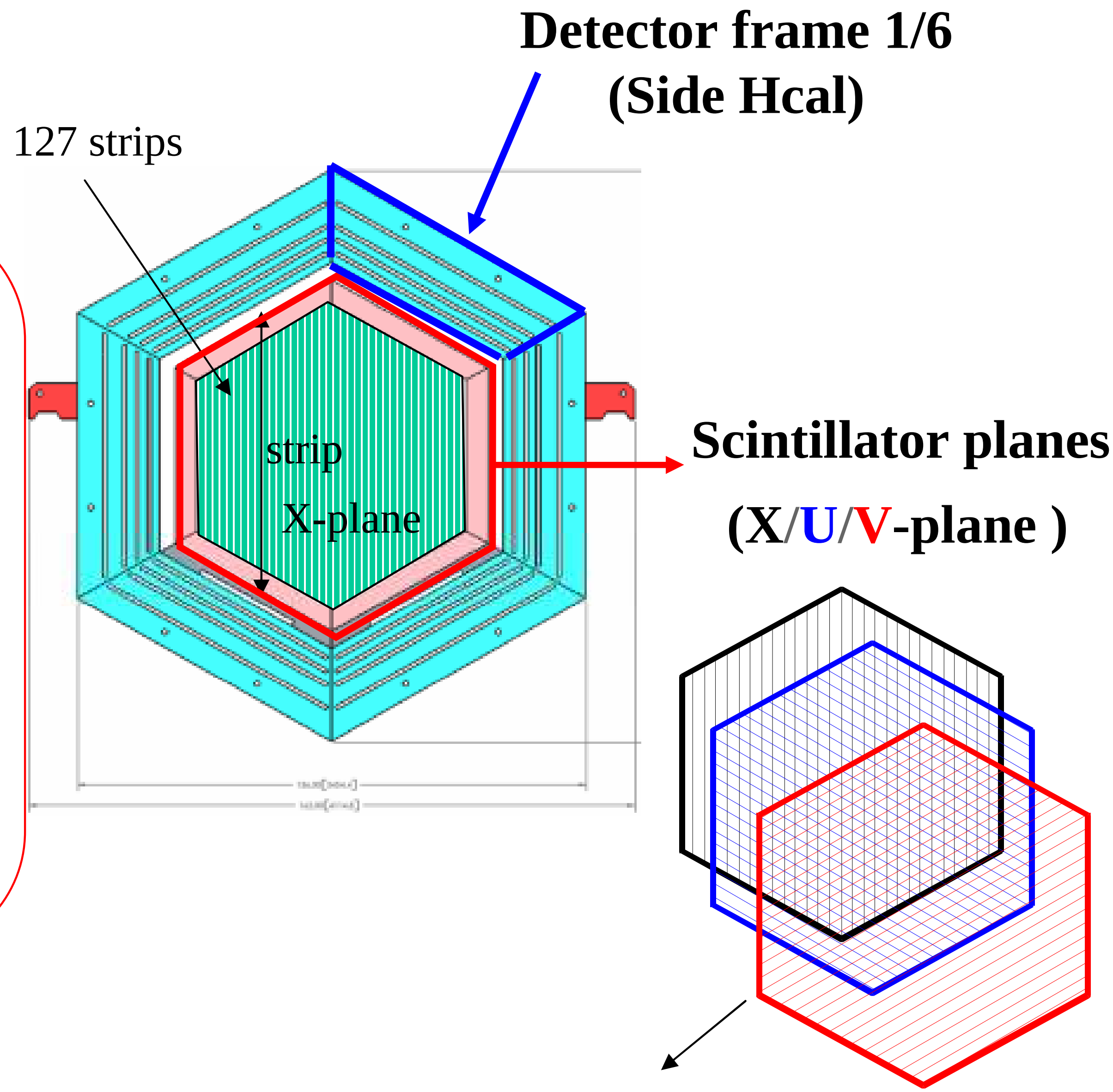
- X_0 (Tracker) ~ 42cm
- X_0 (Ecal) ~ 5cm
- Tracker ~ 6 X_0
- Entire Ecal ~ 8 X_0

Detector Module

Scintillator plane consists of extruded scintillator strips and wavelength shifting fibers





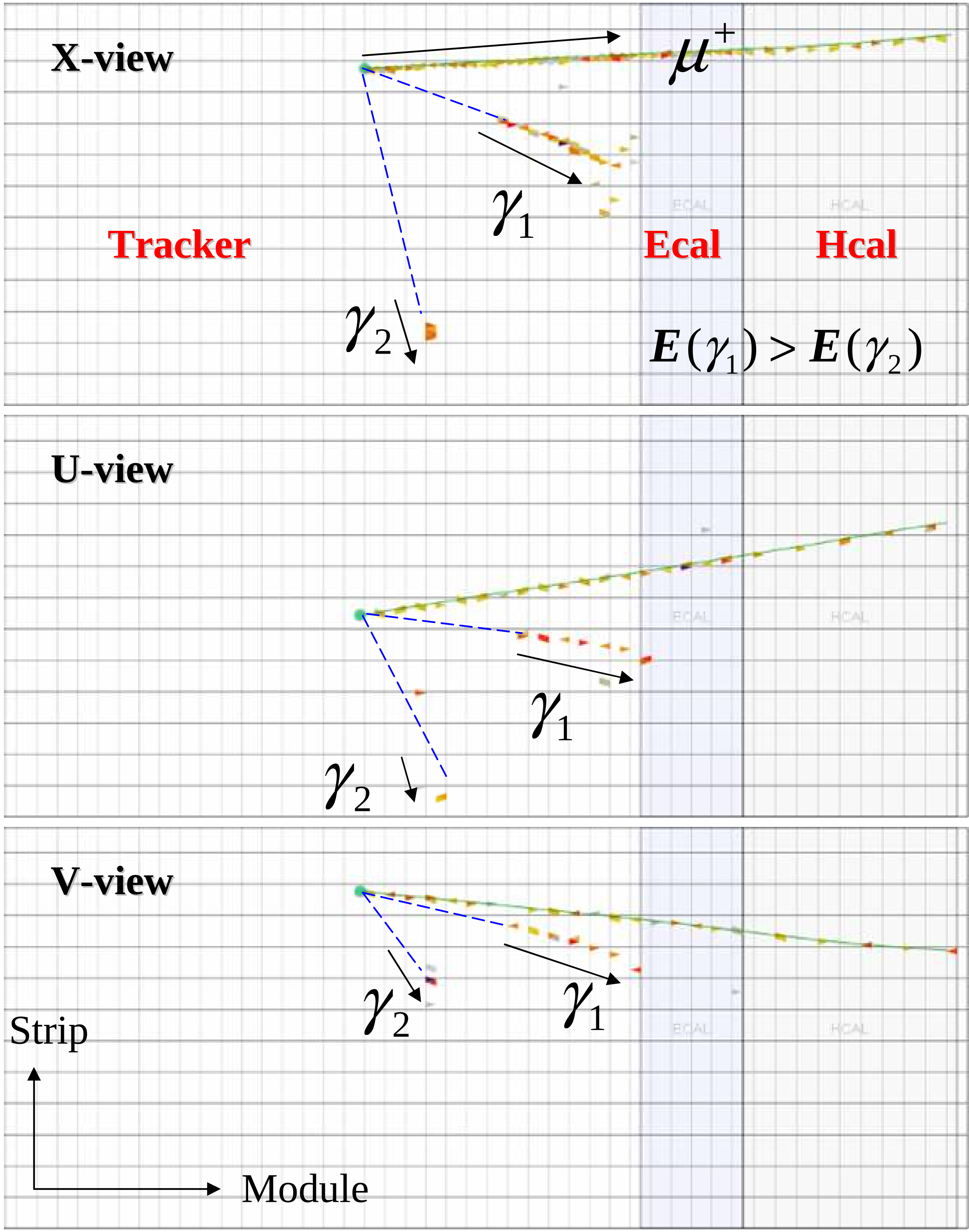


- X, U, V coordinates are combined to make 3D tracking

CC π^0 Reconstruction

$$\bar{\nu}_\mu + p \rightarrow \mu^+ + n + \pi^0$$

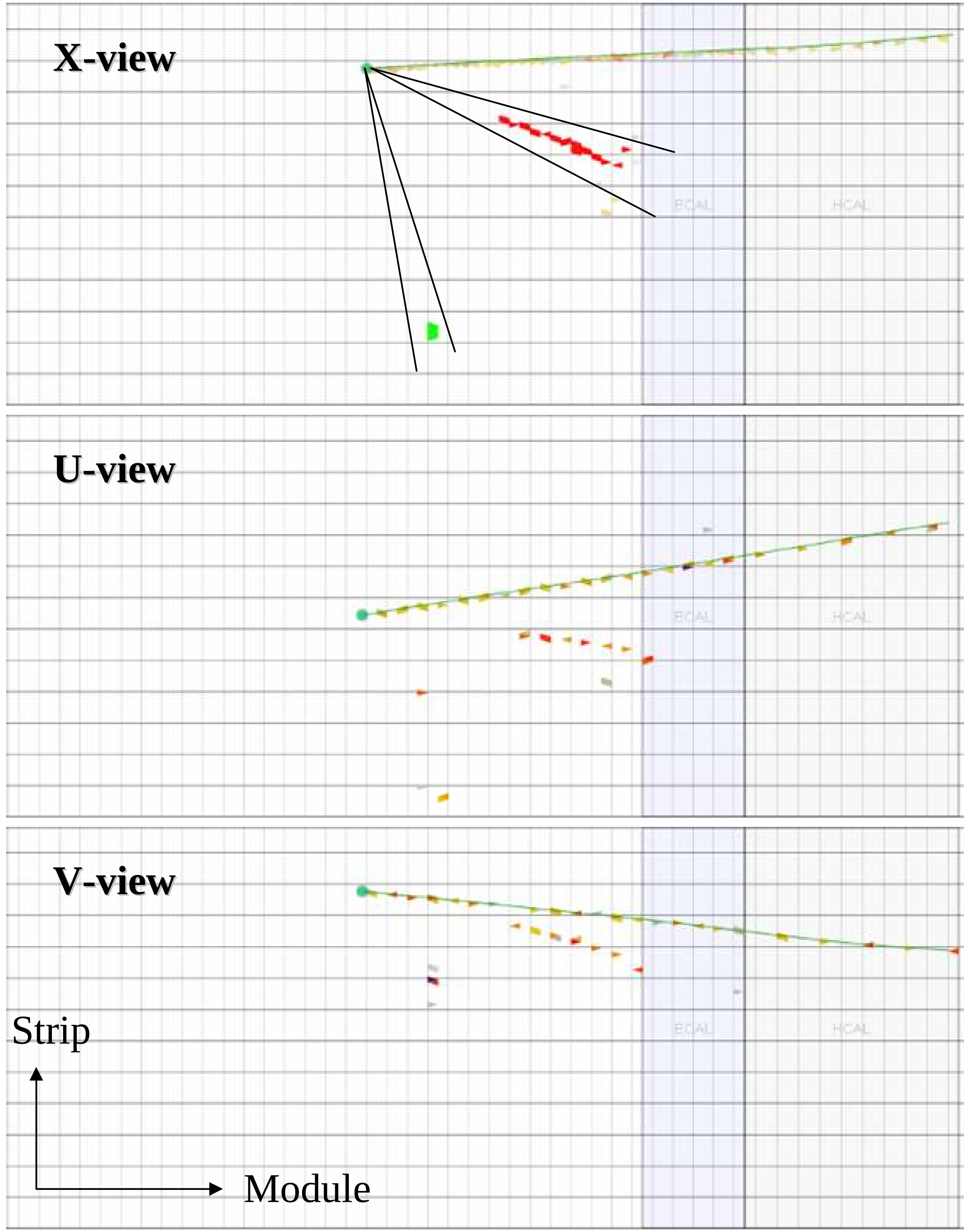
- Neutron is usually not detected
- Muon track vertex constrains π^0 origin



Angular Scan

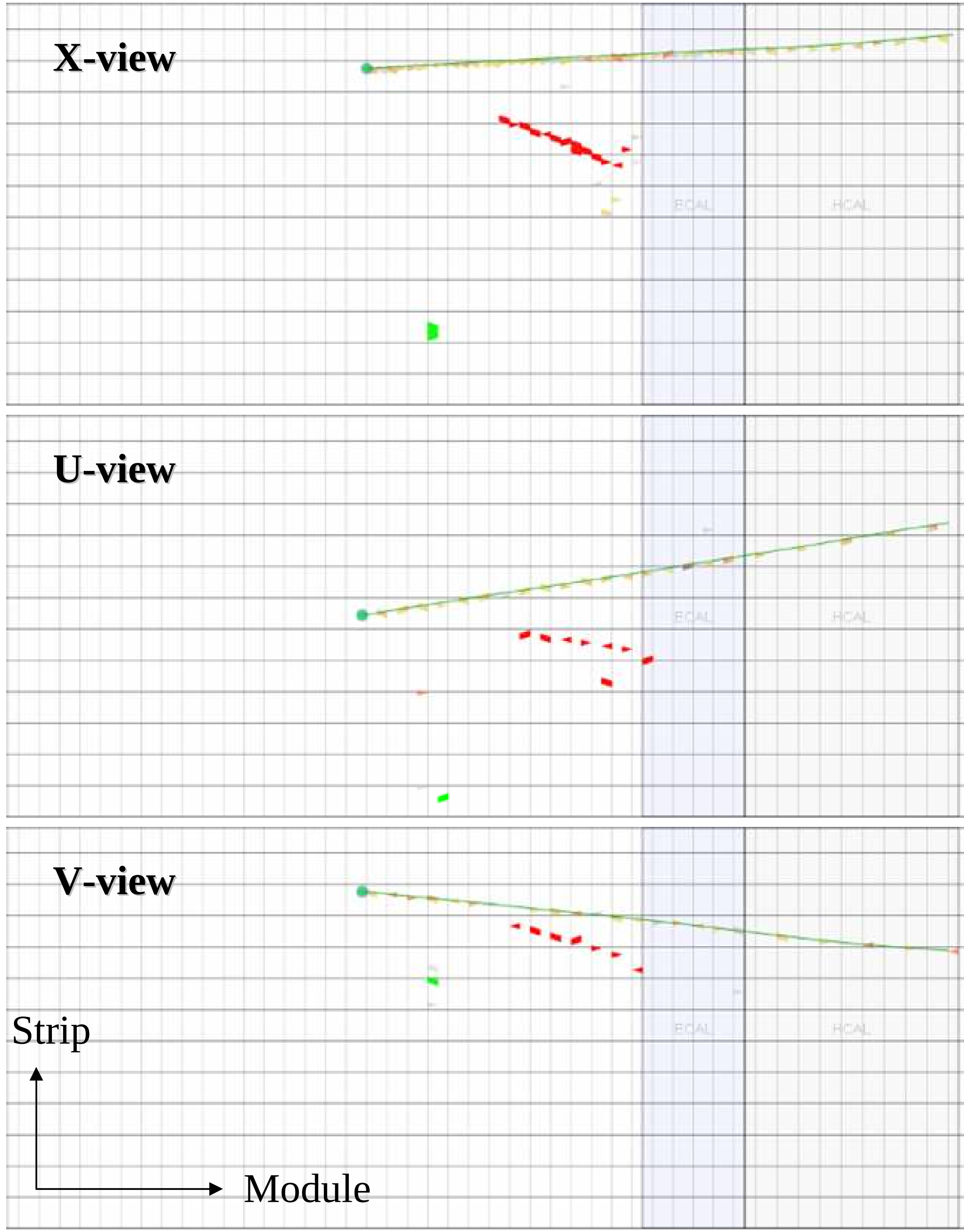
- X-view has better granularity
- Two gammas are most frequently distinguishable in X-view

- Use angular scan to find two separate showers

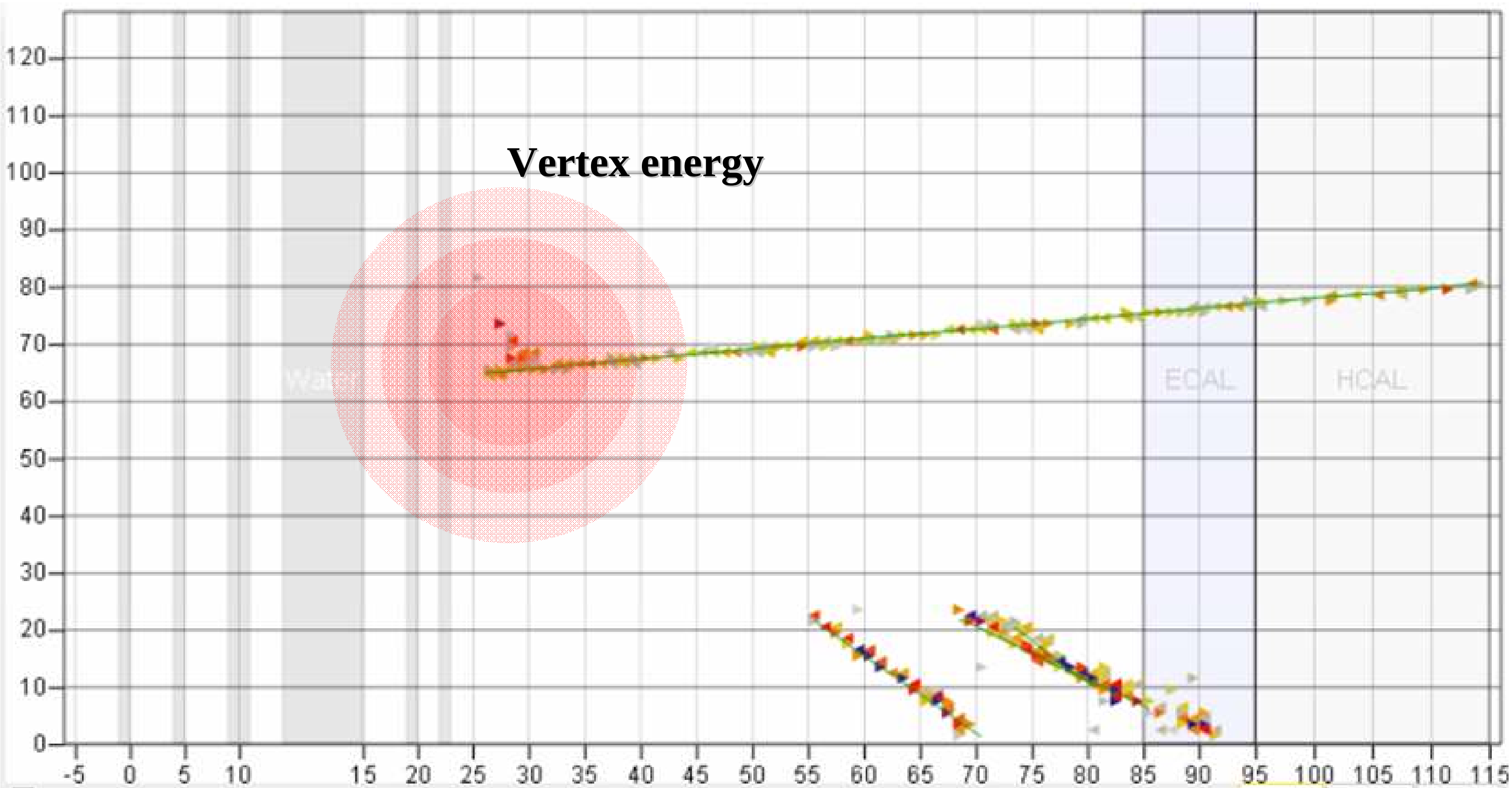


Finding Matching U and V view

- Given X for each z-position, it finds matching U and V coordinates from 4 combinations of U and V
- Matching condition X=U+V

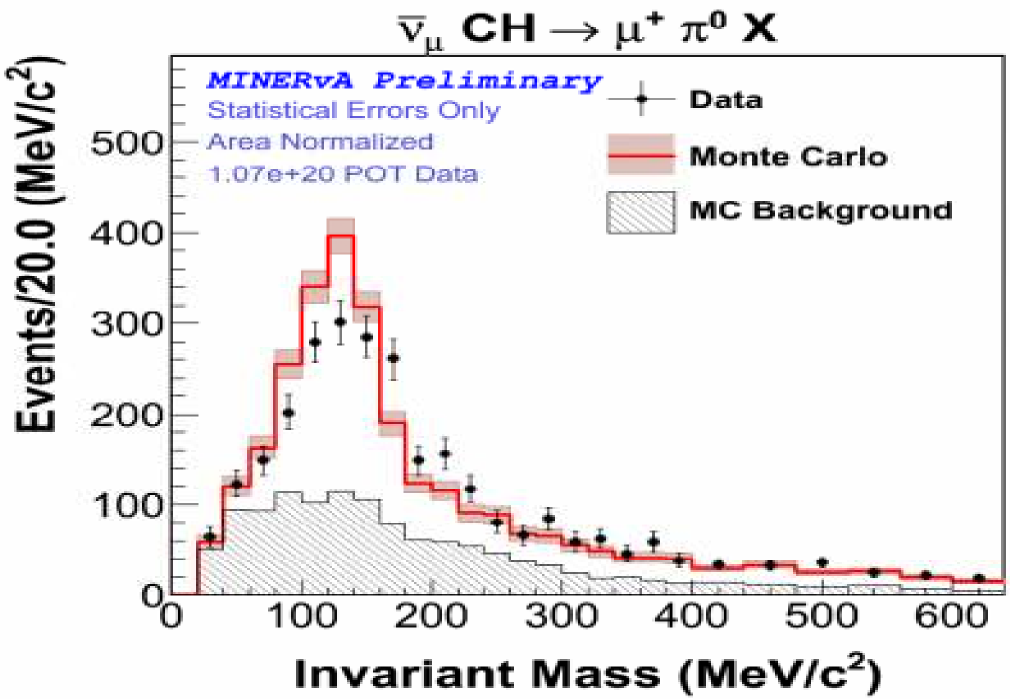


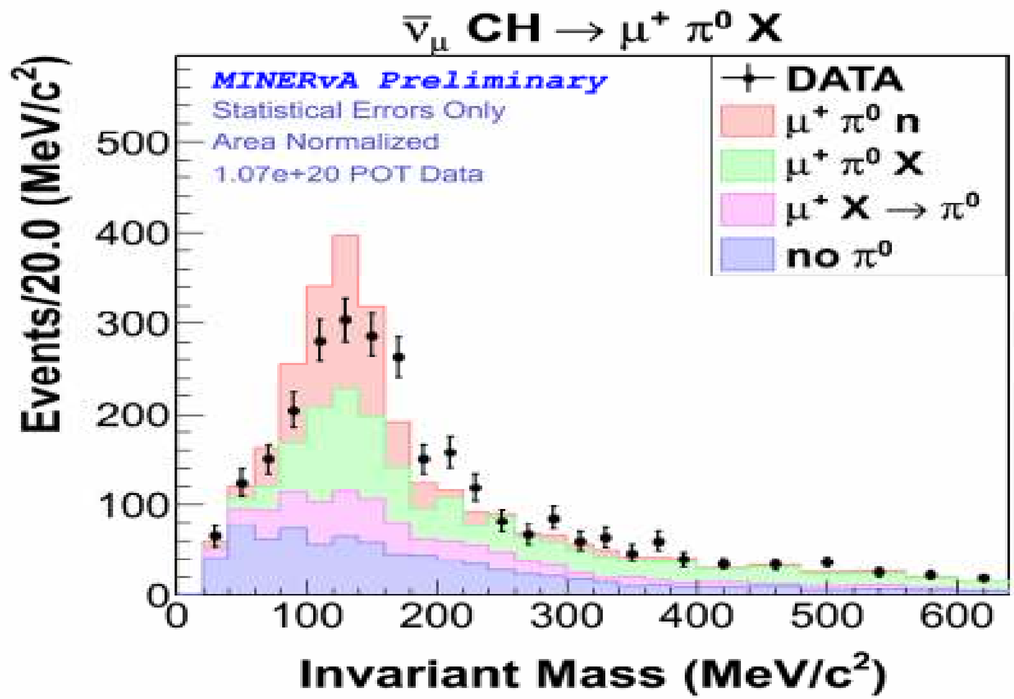
Vertex Energy



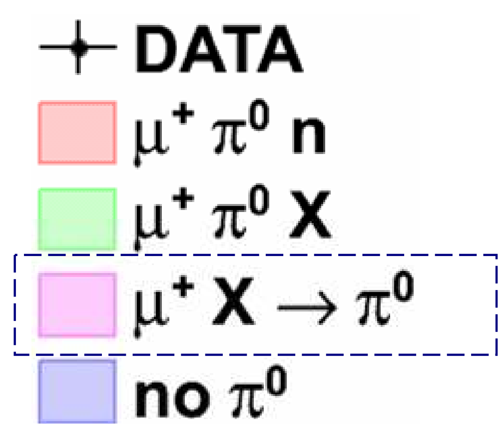
- Vertex energy: energy of activities connected to vertex

CC π^0 Mass Distribution



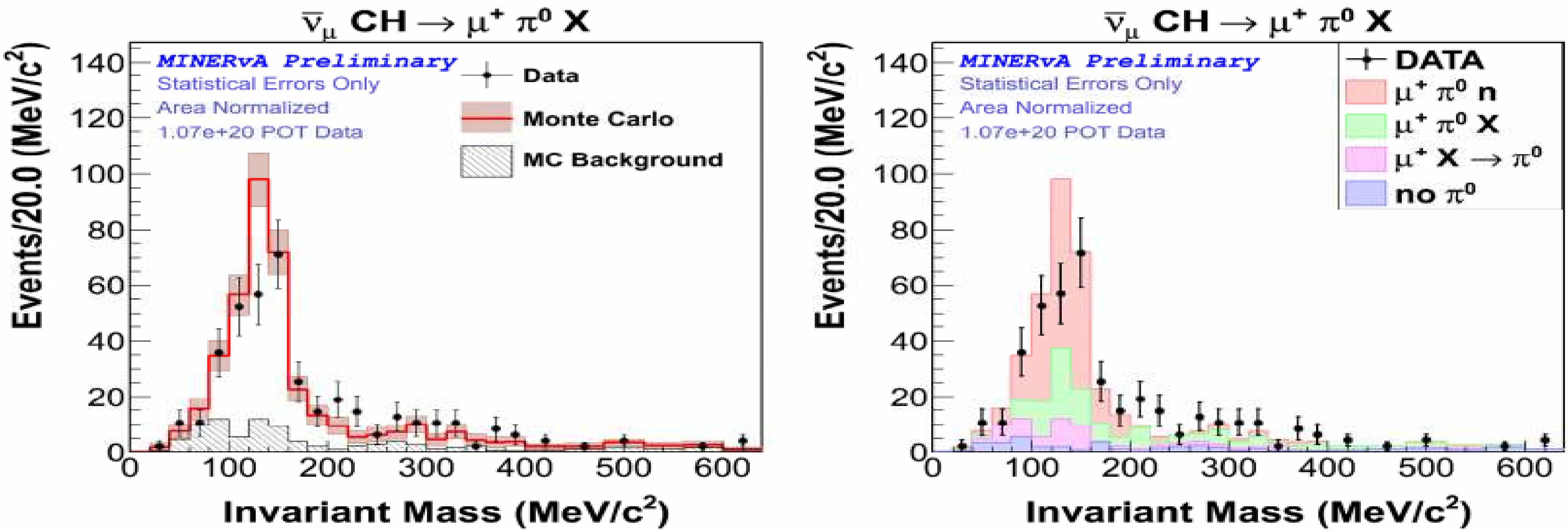


- Anti-neutrino beam
- Anti-muon selected from MINOS
- Anti-neutrino scatters off mainly carbon target (scintillator=CH)



Secondary interaction outside nucleus that produces π^0

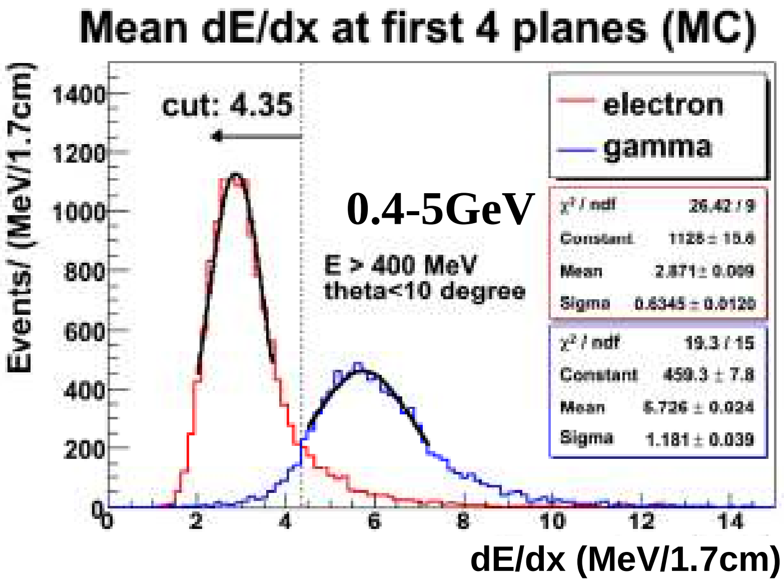
CC π^0 Mass Distribution with dE/dx cut

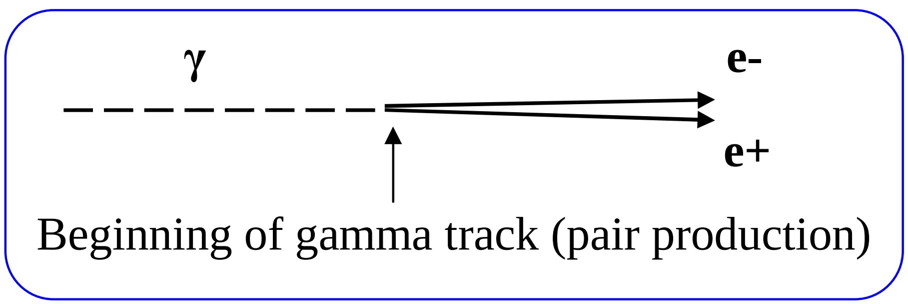


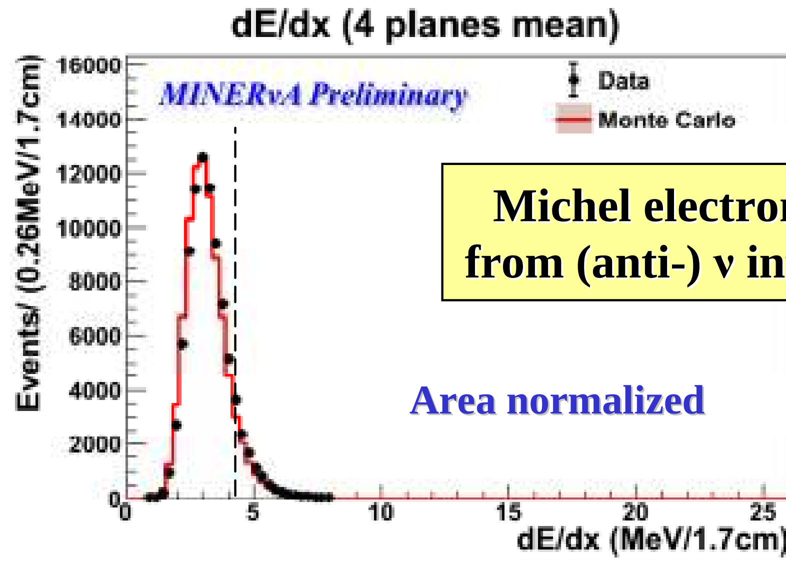
- Narrow peak is near nominal π^0 mass, 135 MeV/c^2
- **dE/dx: 2-12 MeV/1.7cm**
- Vertex energy < 40 MeV

dE/dx for Electron and Gamma Discrimination

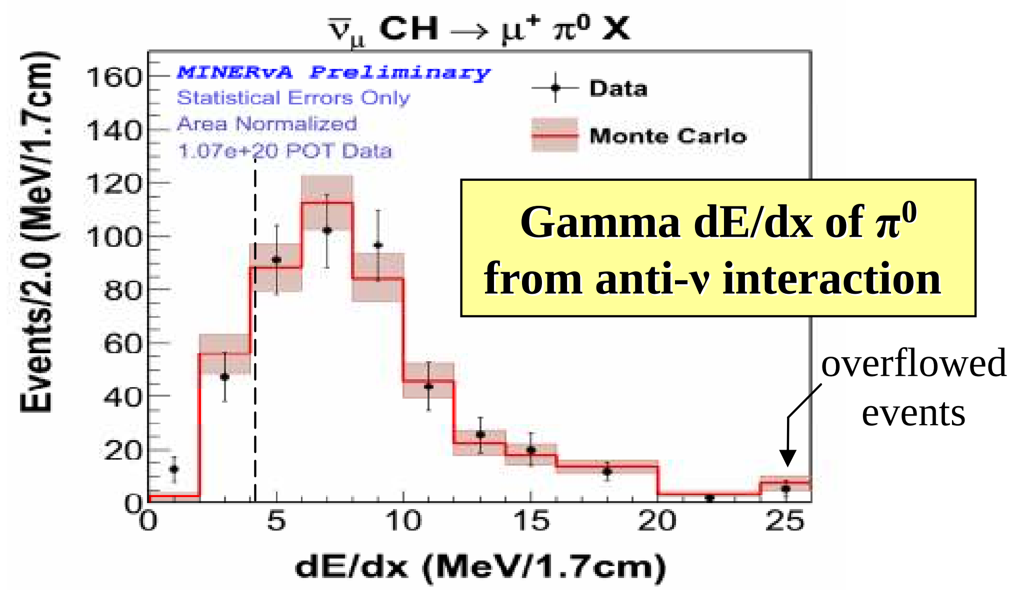
Particle Gun MC







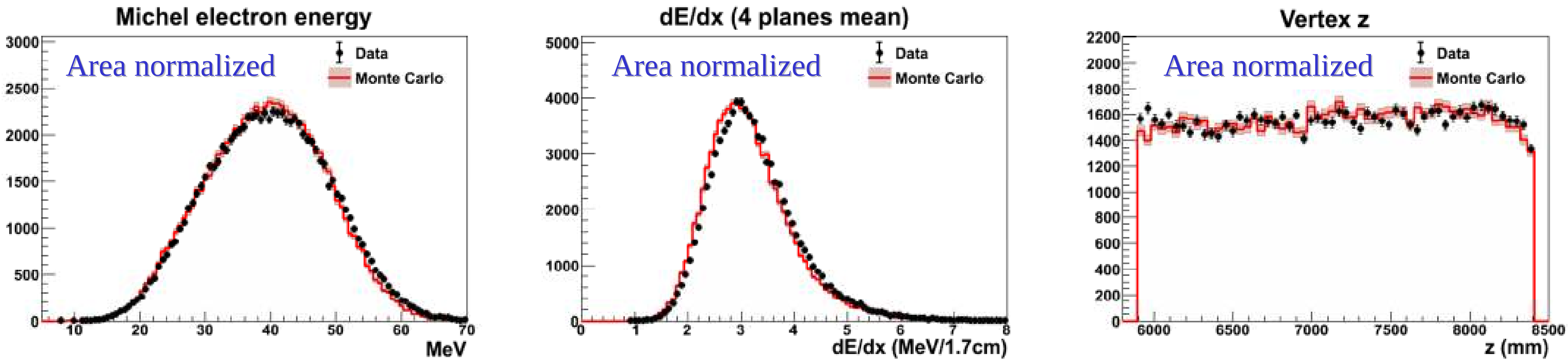
Michel electron dE/dx from (anti-) ν interaction



Gamma dE/dx of π^0 from anti-ν interaction

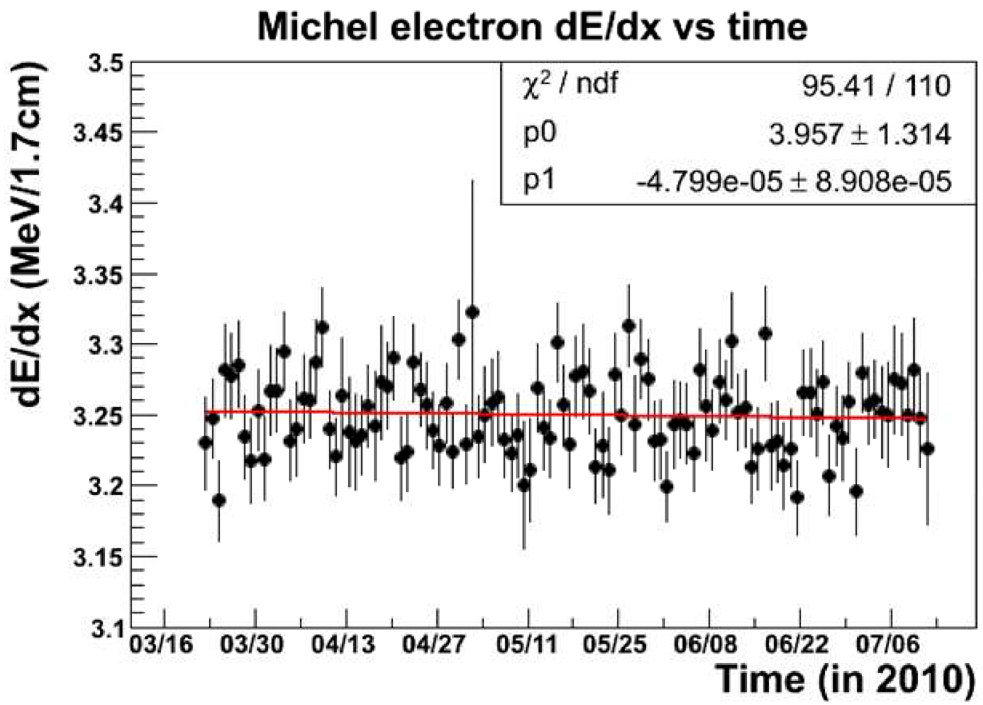
- Neutral current π^0 is decayed into energetic gamma + tiny energy gamma
- dE/dx at the beginning of shower is different for electron and gamma
  - Electron loses energy like MIP (Minimum Ionization Particle)
  - Gamma loses energy like twice MIP

Michel Electron



- Unmatched Michel electrons
- Energy scale check between data and MC
- Nice check on calibration

dE/dx vs time

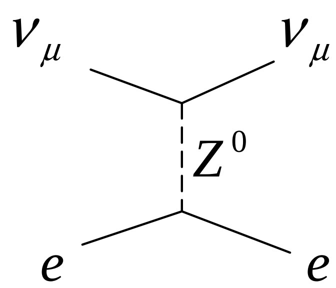


- Slope ((dE/dx)/day)= -4.799E-5 ± 8.908E-5
- Slope is consistent with zero within error of slope
- Energy scale is constant over time

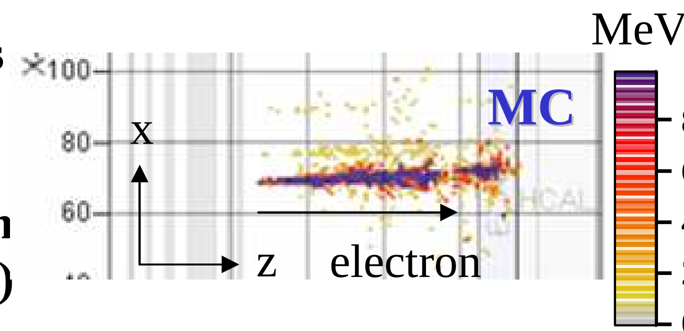
$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ and ν_e CCQE

$$\nu_\mu + e \rightarrow \nu_\mu + e$$

$$\bar{\nu}_\mu + e \rightarrow \bar{\nu}_\mu + e$$



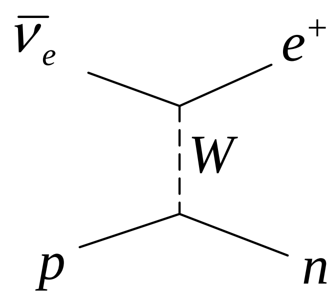
Very clean physics channel but it has tiny cross section. (~1/2000 to neutrin nucleon scattering)



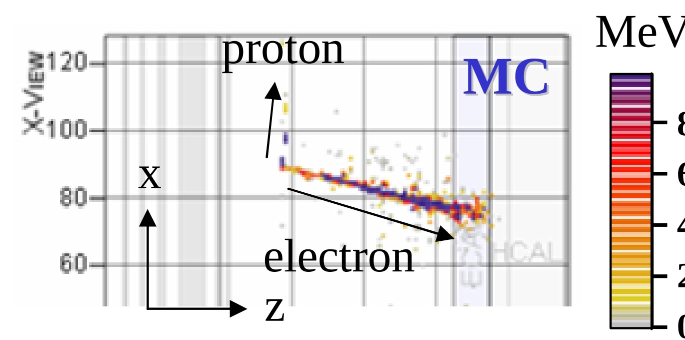
- Well known pure leptonic process is used to get ν_μ flux information
- ν_μ scattering off on light electron has small center of mass energy, so it can have only small momentum transfer, Q^2 , which produces very forward electron final state

$$\nu_e + n \rightarrow e^- + p$$

$$\bar{\nu}_e + p \rightarrow e^+ + n$$



Electron neutrino fraction in flux is small ~ 1%.



- Electron neutrino flux will be measured using charged current quasi-elastic (CCQE) process
- If recoiled nucleon is not observed, two processes look similar

$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$

- Current study is optimized for single electron final states

All can look like single electron final state

$$\nu_\mu + e \rightarrow \nu_\mu + e$$
$$\bar{\nu}_\mu + e \rightarrow \bar{\nu}_\mu + e$$

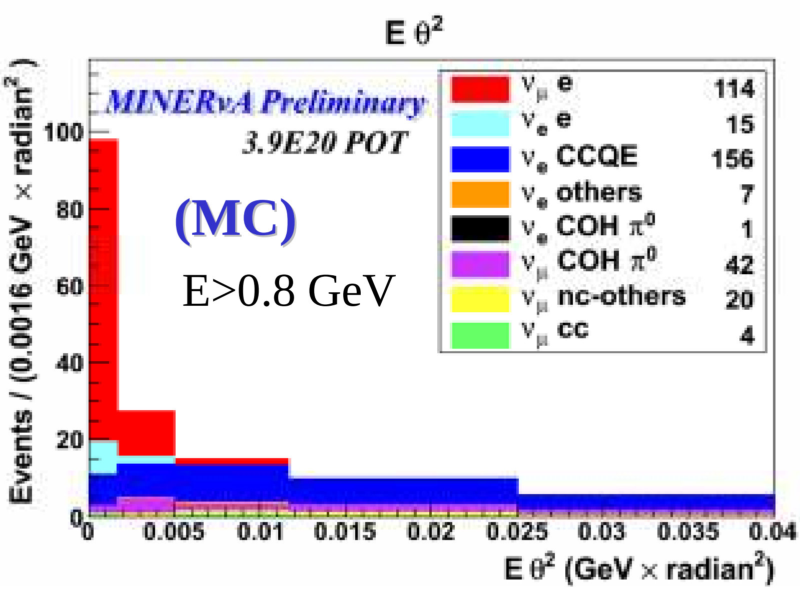
It produces a very forward electron
It can be separated from background using ***Eθ²***

$$\nu_e n \rightarrow e^- p$$
$$\bar{\nu}_e p \rightarrow e^+ n$$

Check vertex activity to reject

$$\nu_\mu A \rightarrow \nu_\mu A \pi^0$$

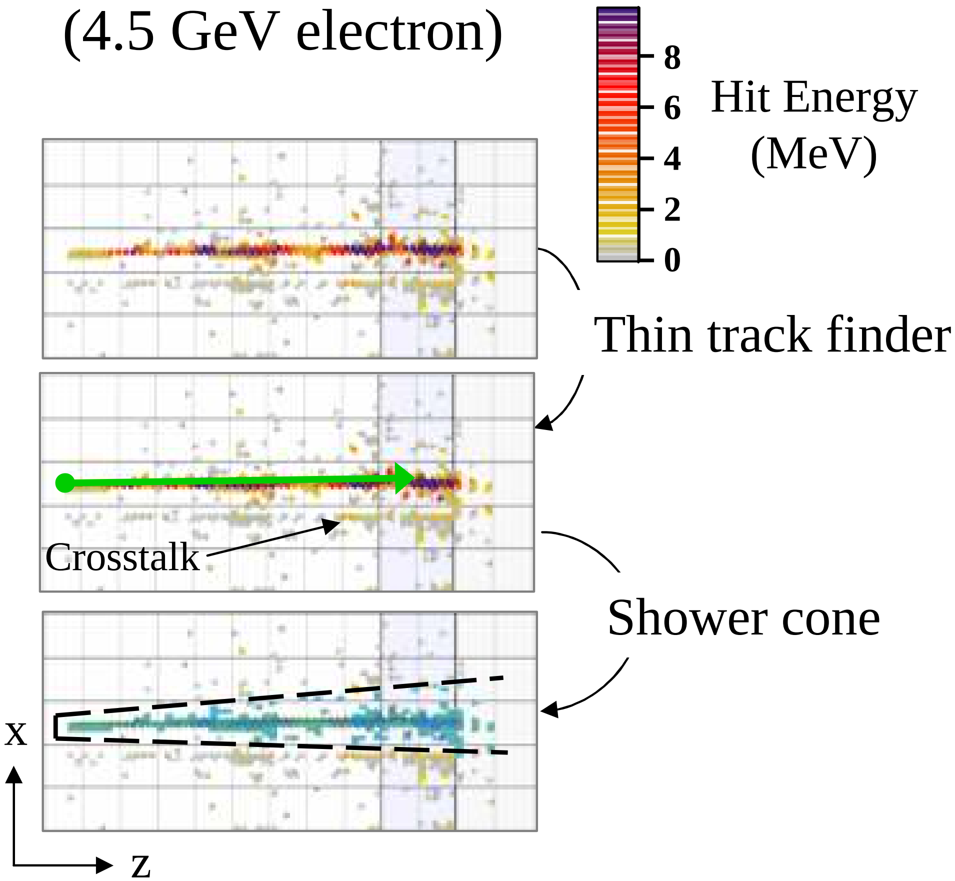
1. Only one of two gammas is detected
   – dE/dx at the beginning is different from electron
2. High energy π^0 decays into two gammas with very small opening angle
   – Check transverse energy distribution



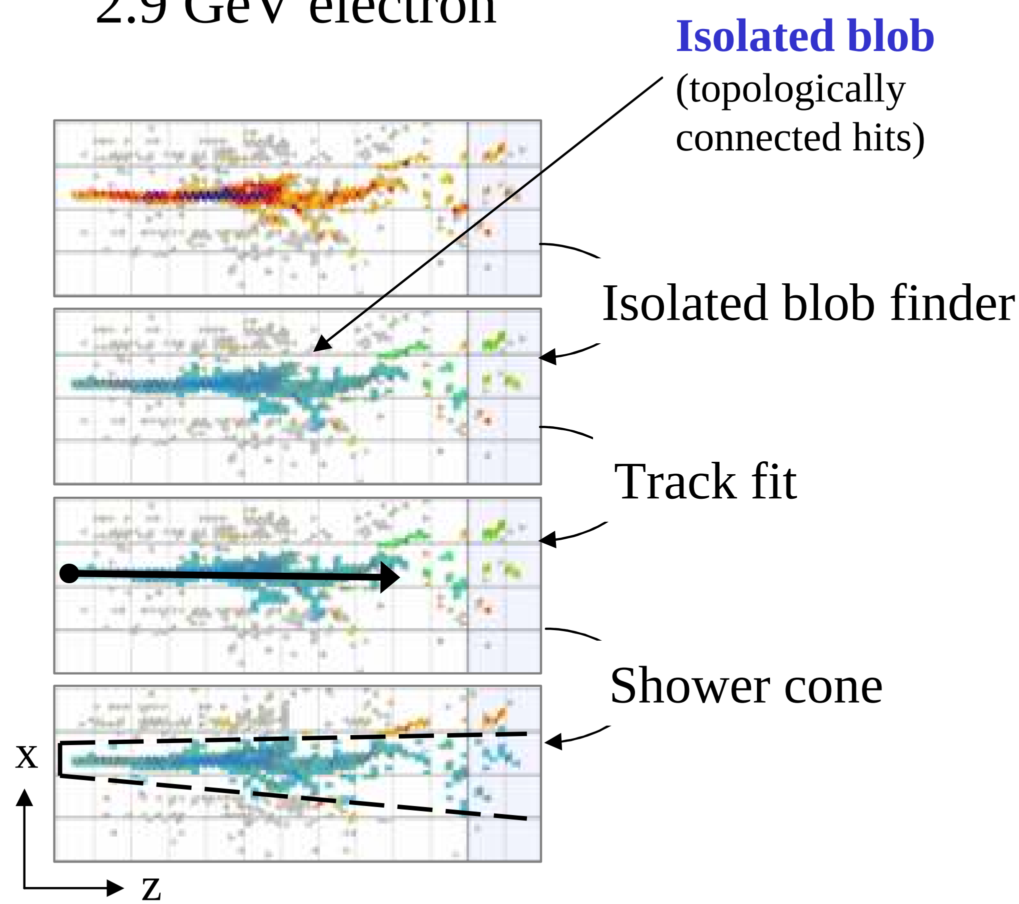
E: Energy of electron candidate
θ: Theta of electron candidates w.r.t. beam direction

Single EM Shower Reconstruction

Track-like shower
(4.5 GeV electron)

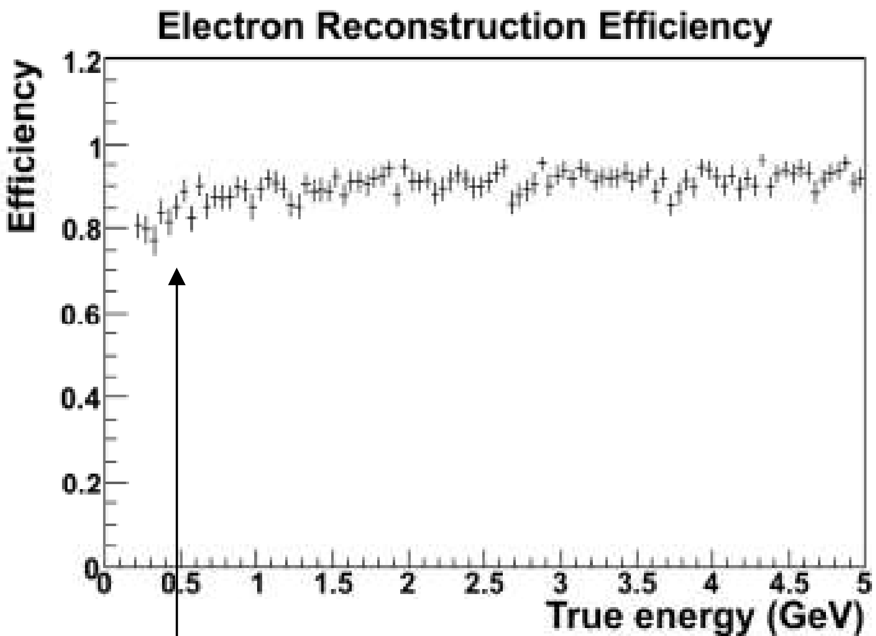


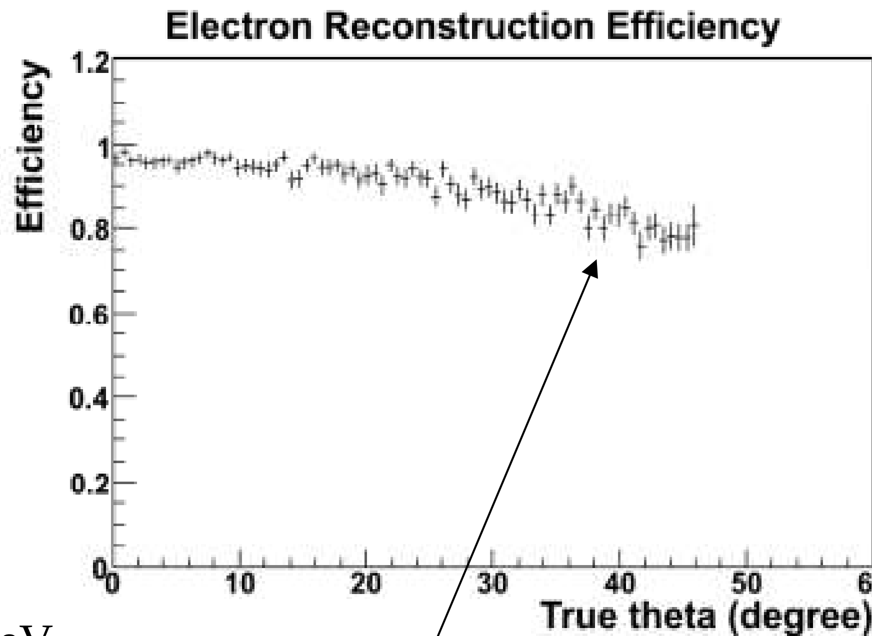
Fuzzy shower
2.9 GeV electron



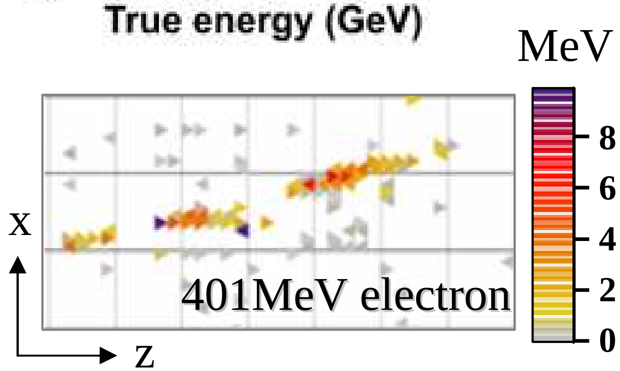
- Once vertex and direction is known, shower cone can be applied
- When (thin) track finder fails on fuzzy shower, isolated blob finder is used and then track fitter can handle fuzzy shower

MC Reconstruction Efficiency





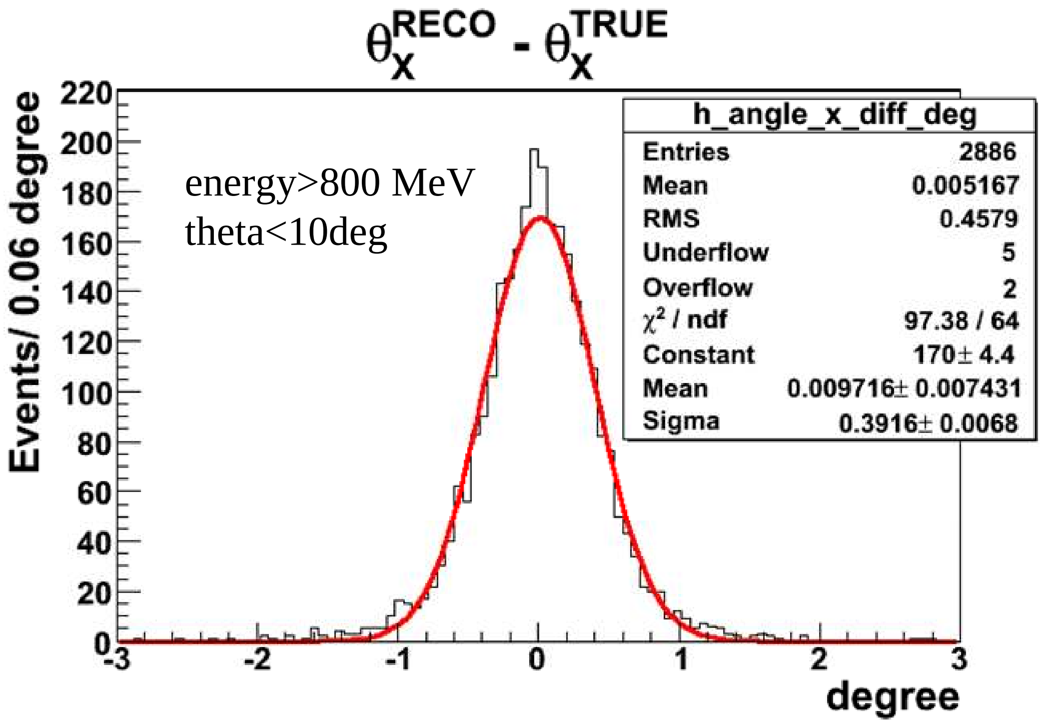
Low energy electron sometimes produces gappy shower

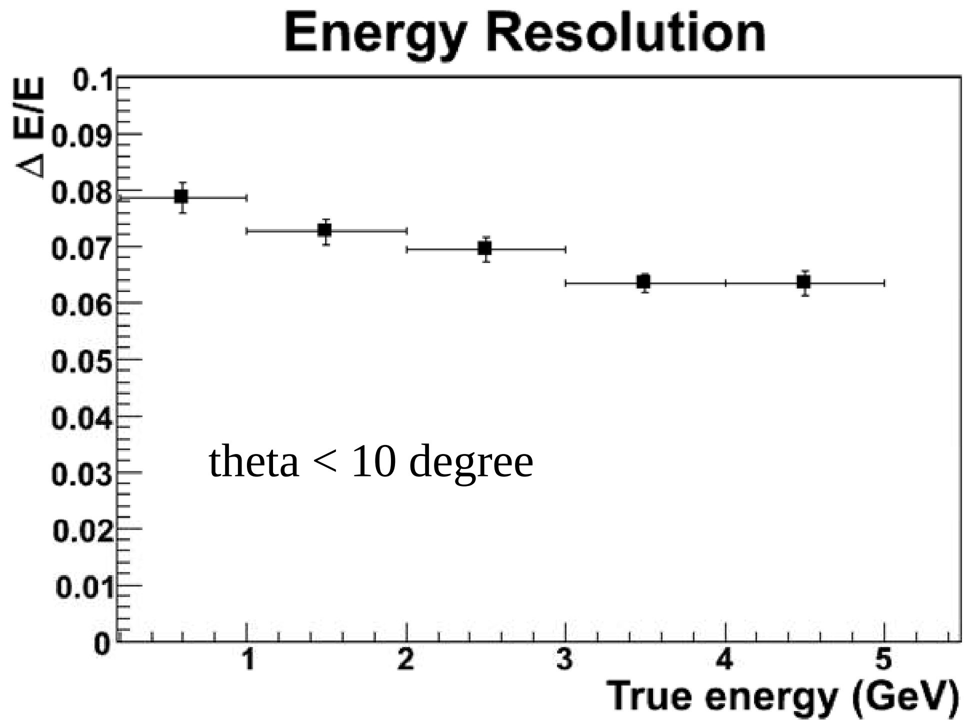


Big theta angle electron tends to exit to sides, which leaves less hits in tracking volume

- Electron particle gun is used to calculate efficiency
  - Energy: 0.2 ~ 5 GeV, Theta: 0~45 deg
- **Reconstruction efficiency is 0.96 for small angle** (angle <10 degree, energy>400MeV)

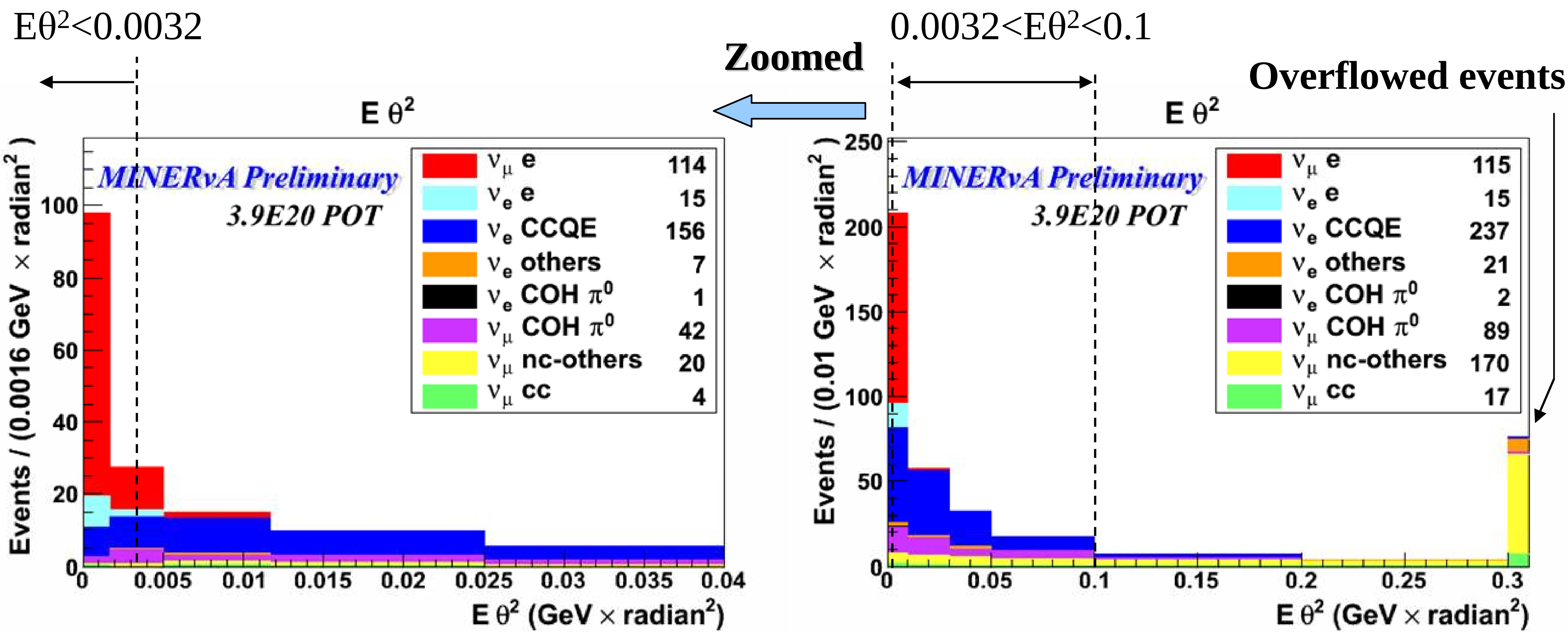
MC Angular and Energy Resolution





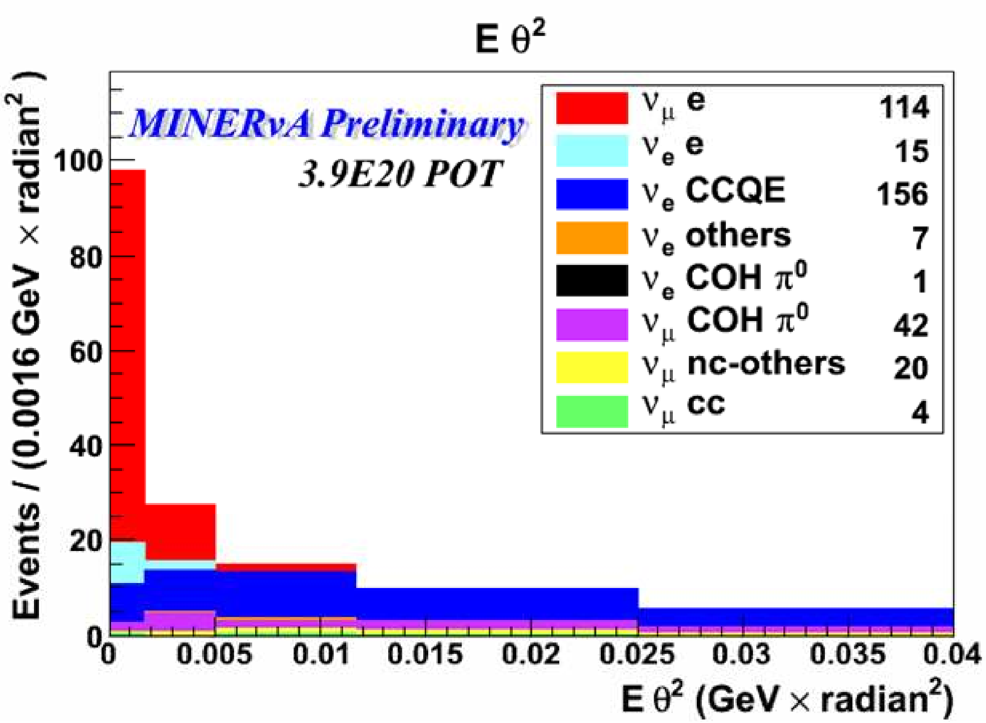
- X-angle resolution ~ 0.4 degree
- Precise angular reconstruction is critical to separate ν_μ *e* elastic scattering from ν_e CCQE
- Energy resolution: 6~ 7%

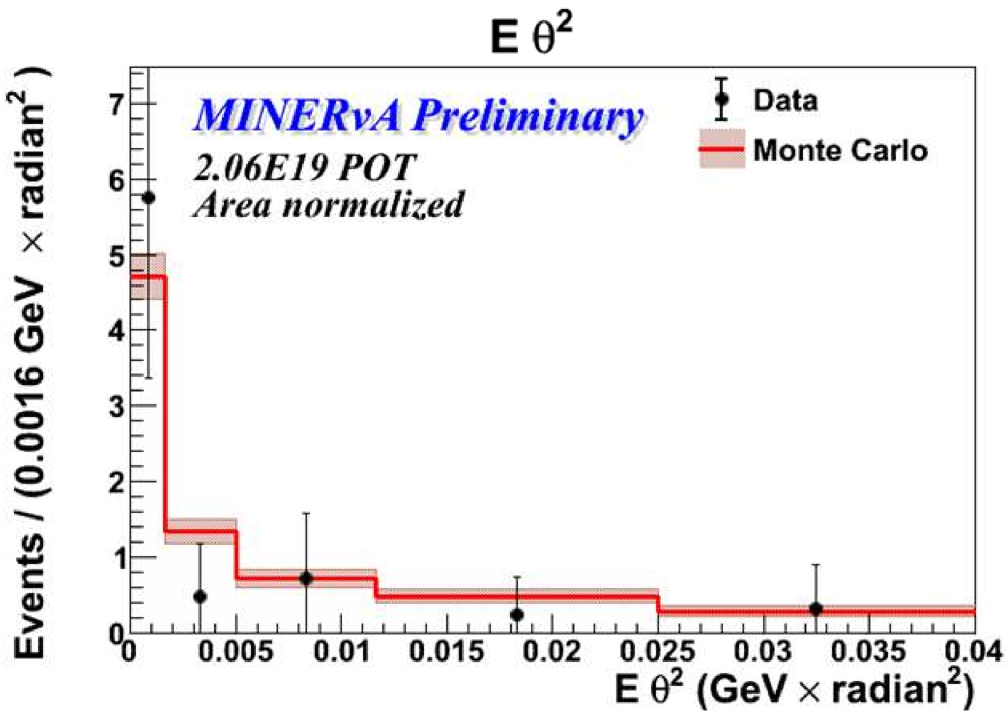
$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ and ν_e CCQE



- Neutrino beam
- $E\theta^2 < 0.1$ GeV·radian^2 cut is used to remove background
- $E\theta^2$ is divided into two regions
  - $E\theta^2<0.0032$: $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ rich region
  - $0.0032<E\theta^2<0.1$: ν_e CCQE rich region

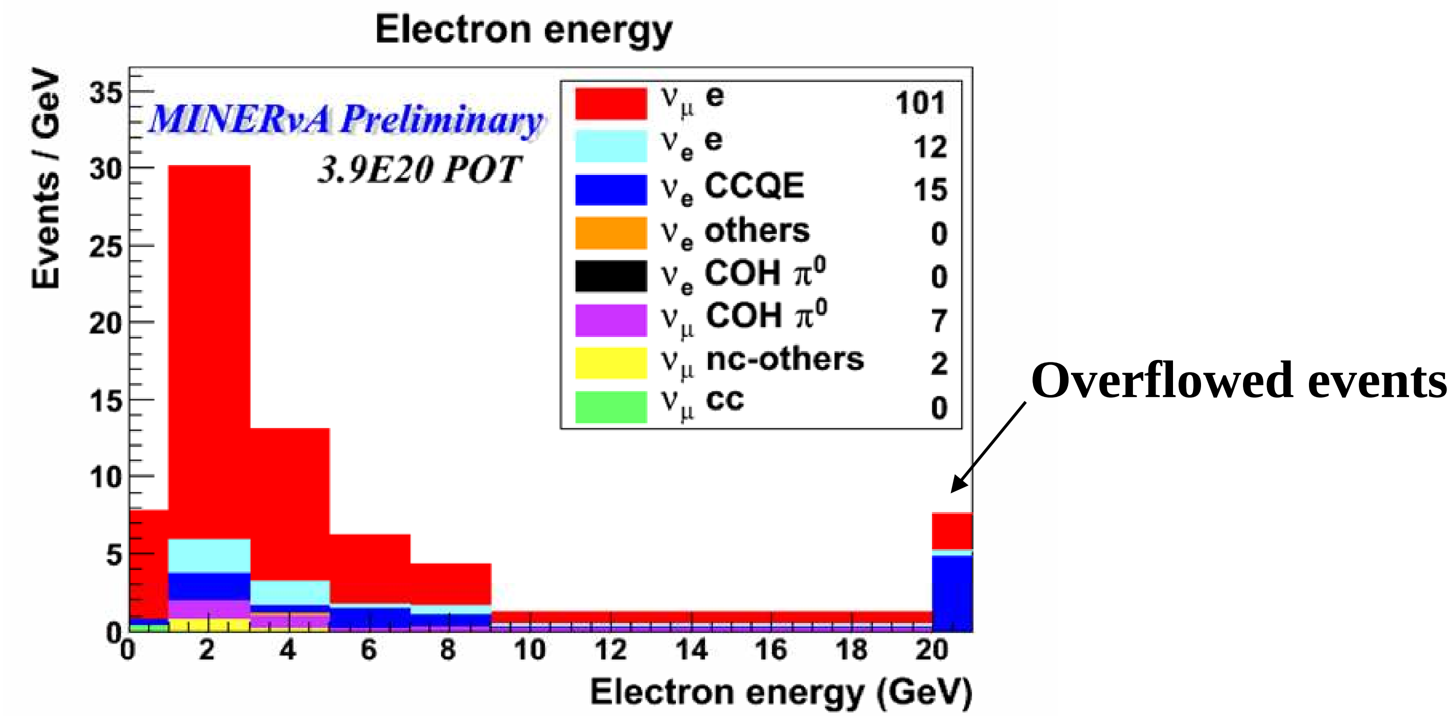
Small Sample Data/MC comparison





- Small data (~ 5% to full data) is used for comparison
- Peak in low Eθ^2 is found in data

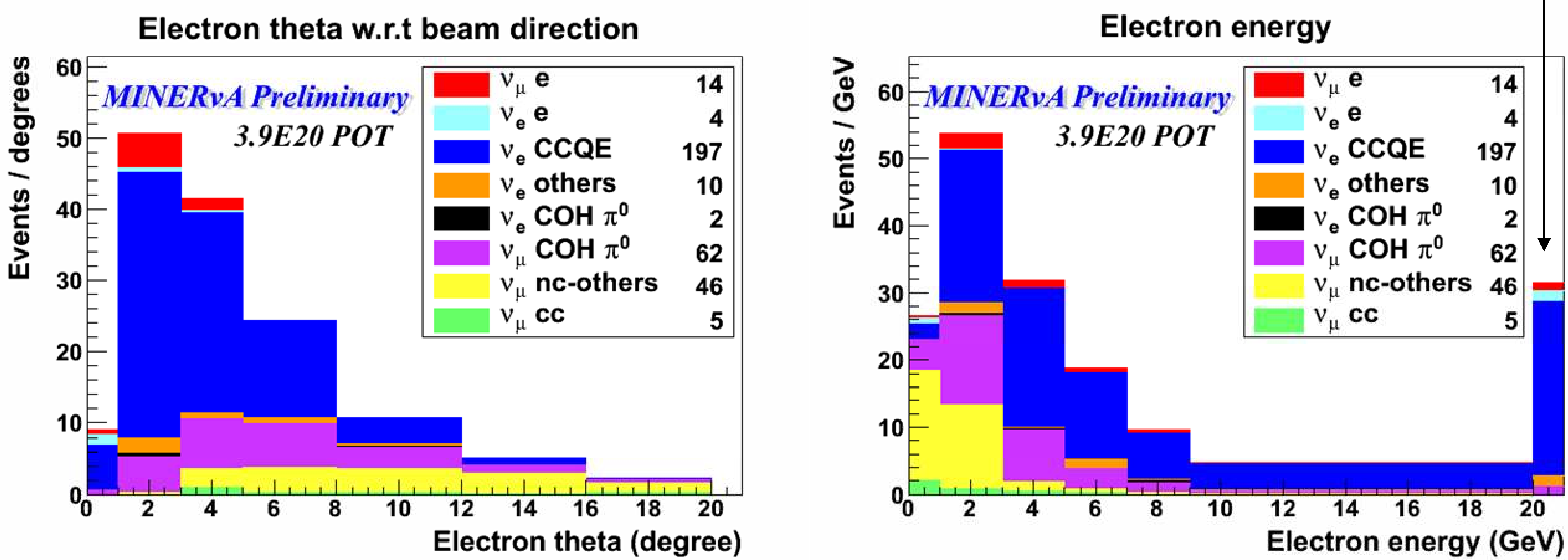
Electron spectrum of $\nu+e^-$ Elastic Scattering



- $E\theta^2<0.0032$: $\nu_\mu+e^-\rightarrow \nu_\mu+e^-$ rich region
- Purity: 0.82, efficiency: 0.6
- Expected signal (**$\nu_\mu+e^-$, ν_e+e^-**) is 112 events with 24 background events
- It gives ~10% statistical error on flux constraint

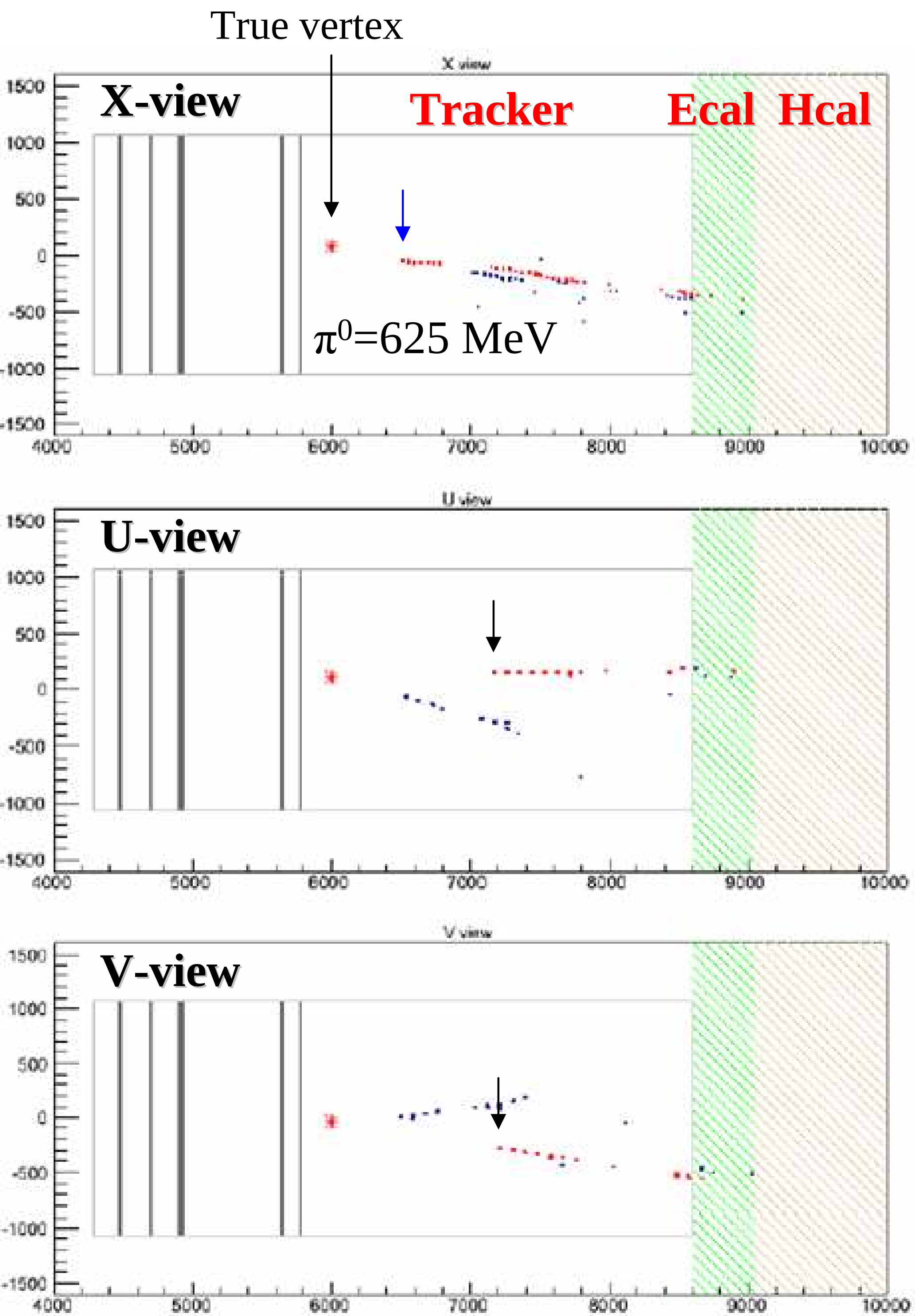
ν_e CCQE

Overflowed events

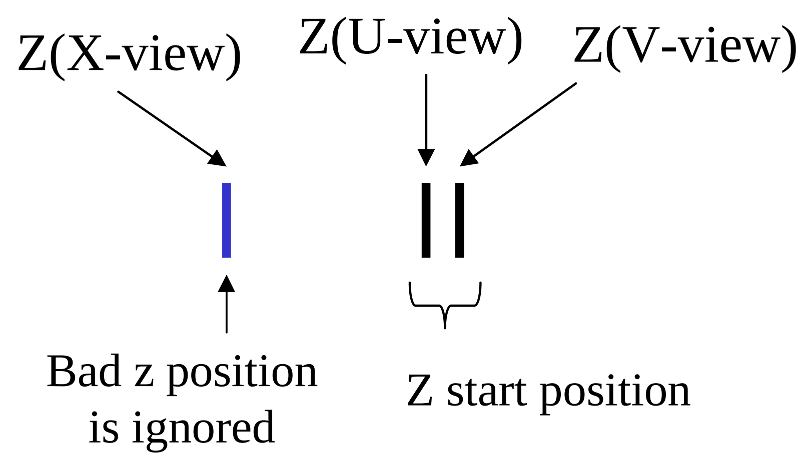


- $0.0032<E\theta^2<0.1$: ν_e CCQE rich region
- Purity: 0.58, Efficiency: 0.06
- Efficiency is very low now because cuts are optimized for clean single electron final state with no vertex activity
- High energy tail is more pure ν_e CCQE

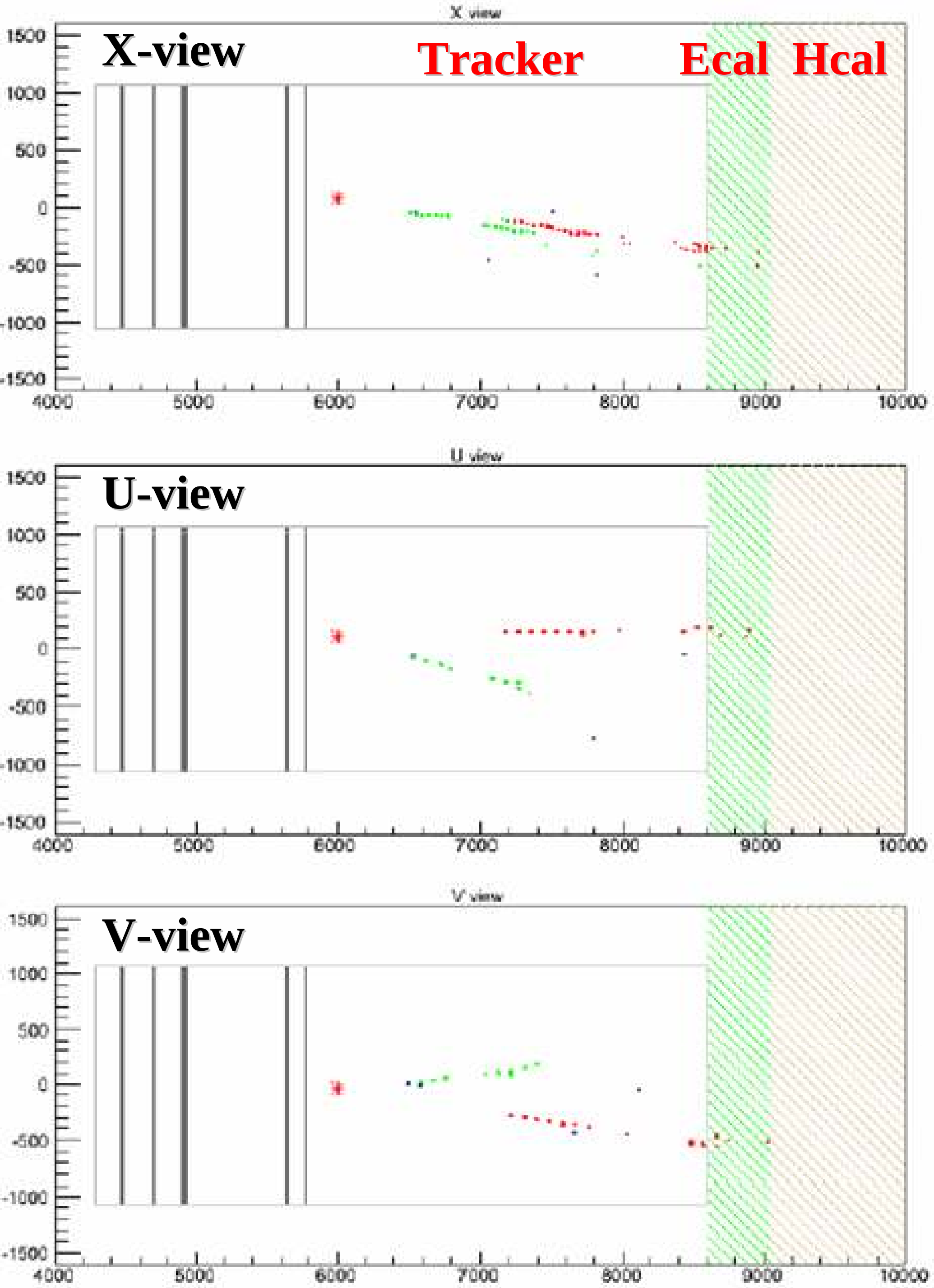
NC π^0 Reconstruction (Preliminary)



- Run Hough 2D Transform to get straight lines for each views
- Z-start position matching



NC π^0 Reconstruction (Preliminary)



- Apply shower cone using start position for each photons
- Two photons are nicely separated

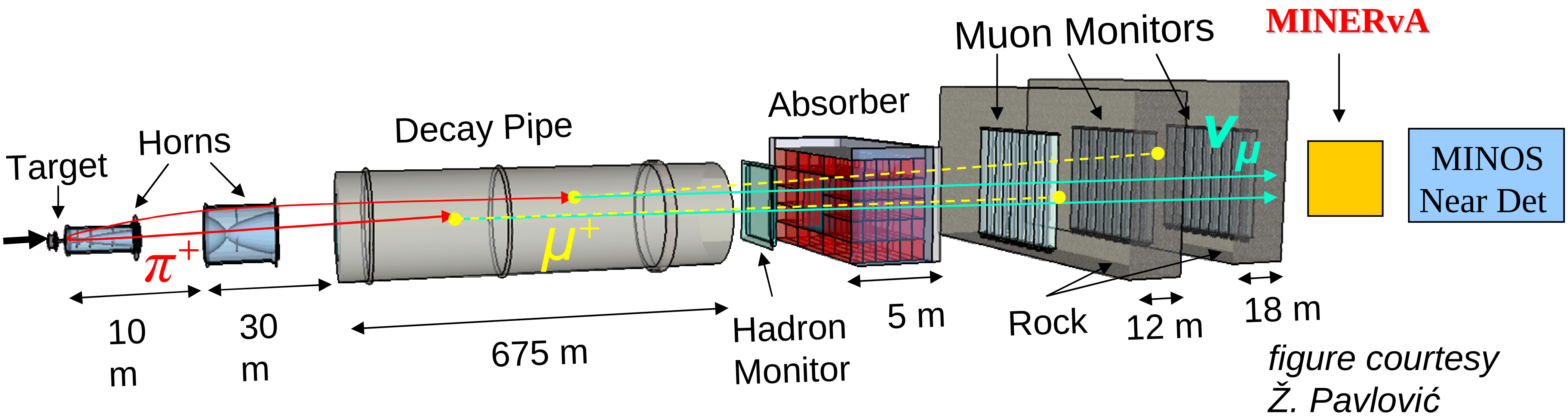
Summary

- Various EM final states are important for neutrino oscillation experiment
- CC $1\pi^0$ and single electron reconstruction tools are developed and we're looking at data and MC consistency
- NC π^0 and other EM final states are also being studied

Thank You!

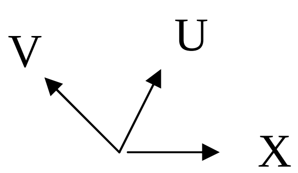
(Backup Slides)

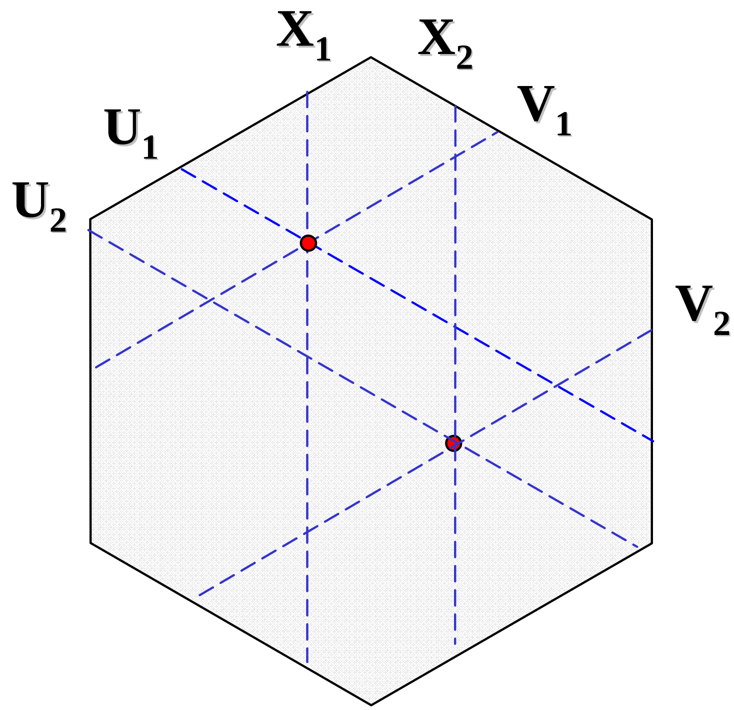
NuMI Beamline



- Movable targets to configure beam energy (low energy, medium energy etc)
- Horn current to select sign of neutrino
  - Forward horn current: neutrino dominant beam
  - Reverse horn current: anti-neutrino dominant beam

X, U, V-view Matching

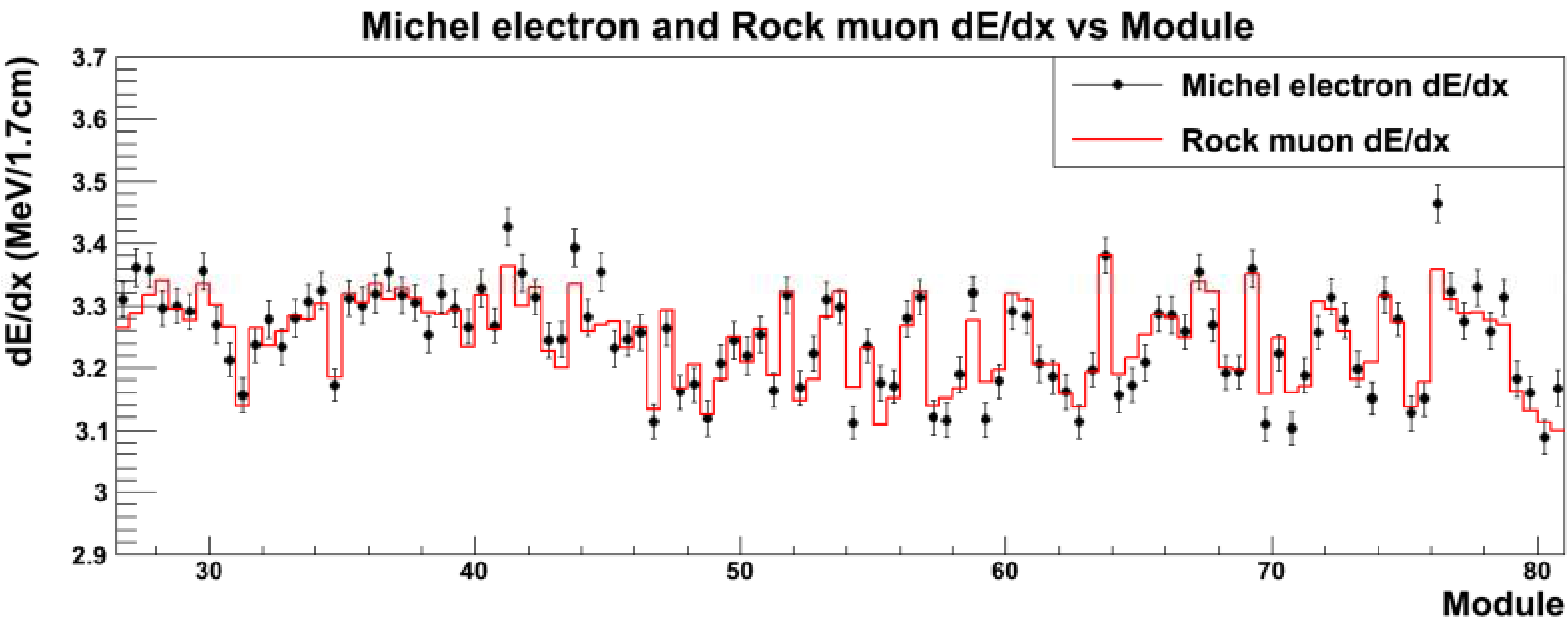




$U_1+V_1 = X_1$
$U_1+V_2 \neq X_1$
$U_2+V_1 \neq X_1$
$U_2+V_2 \neq X_1$

- Lower energy, γ_2 often has steep angle and it doesn't leave hits in all three views
- Just 2-view matching is used for that

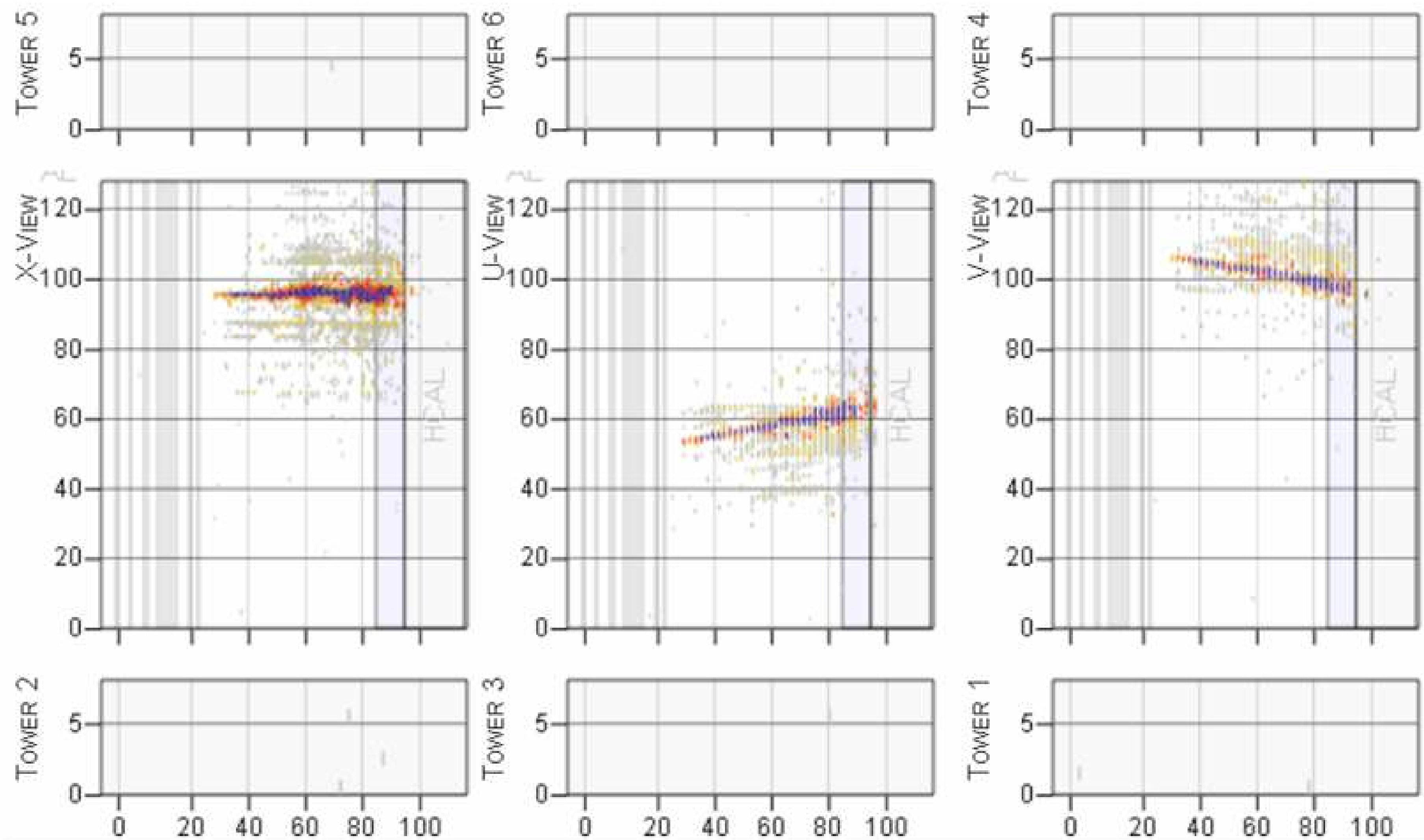
Each planes’ dE/dx from Michel electrons and rock muons



- Plane to plane variation is consistent between Michel electron and rock muon dE/dx

$\nu + e^-$ Elastic Scattering

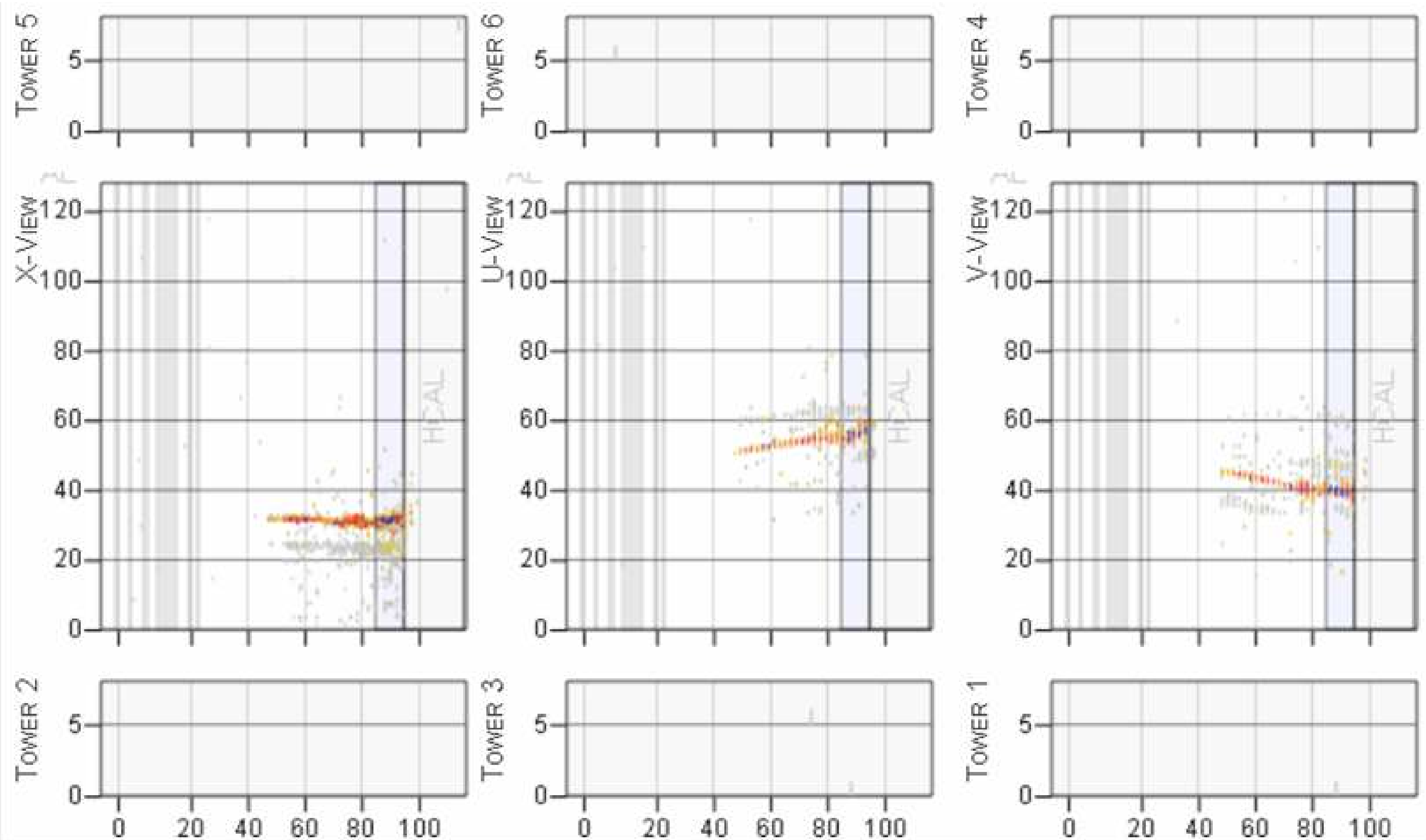
10002|125|1749



$\nu + e^-$ Elastic Scattering

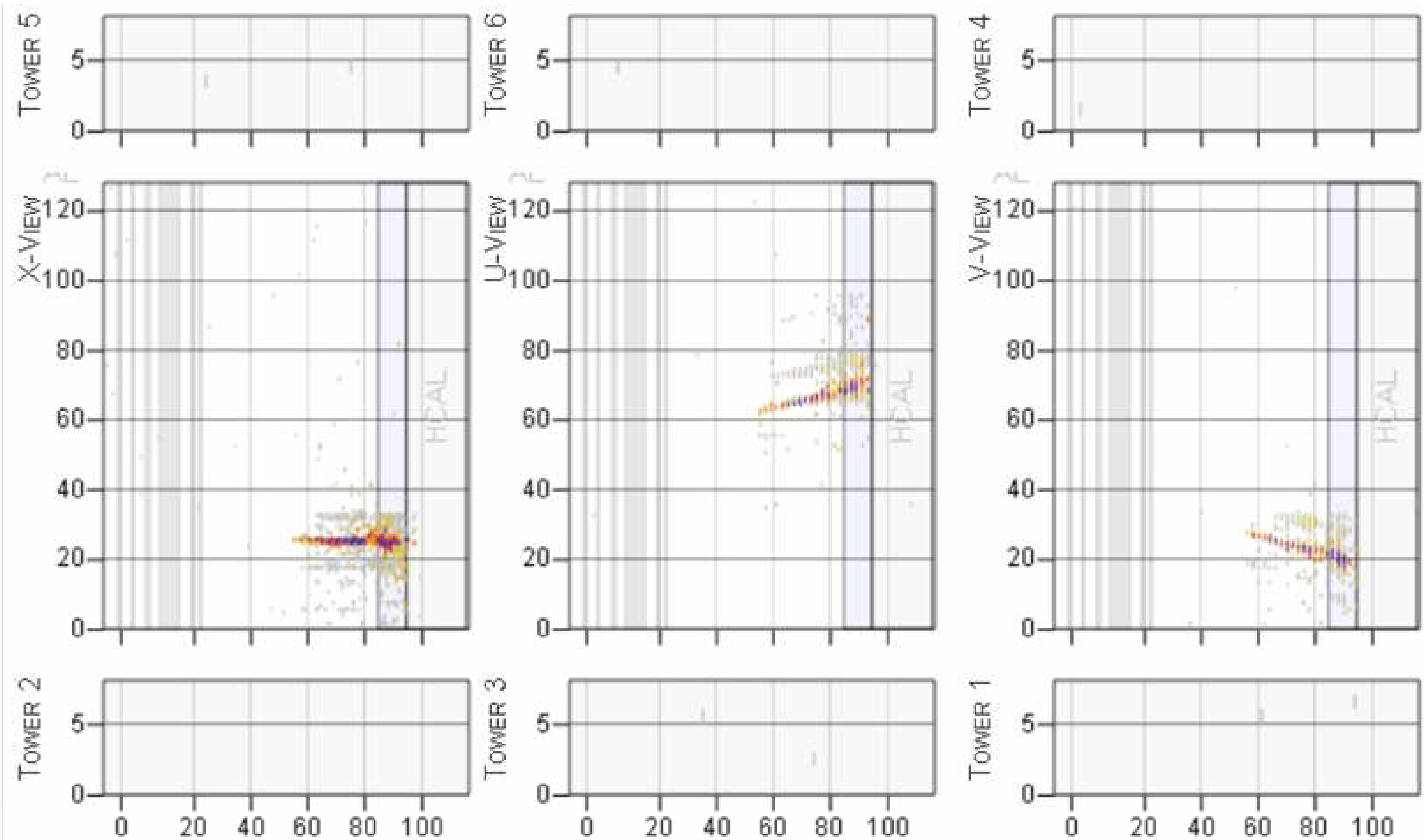
Electron KE=3743.4 MeV

10003|87|1767



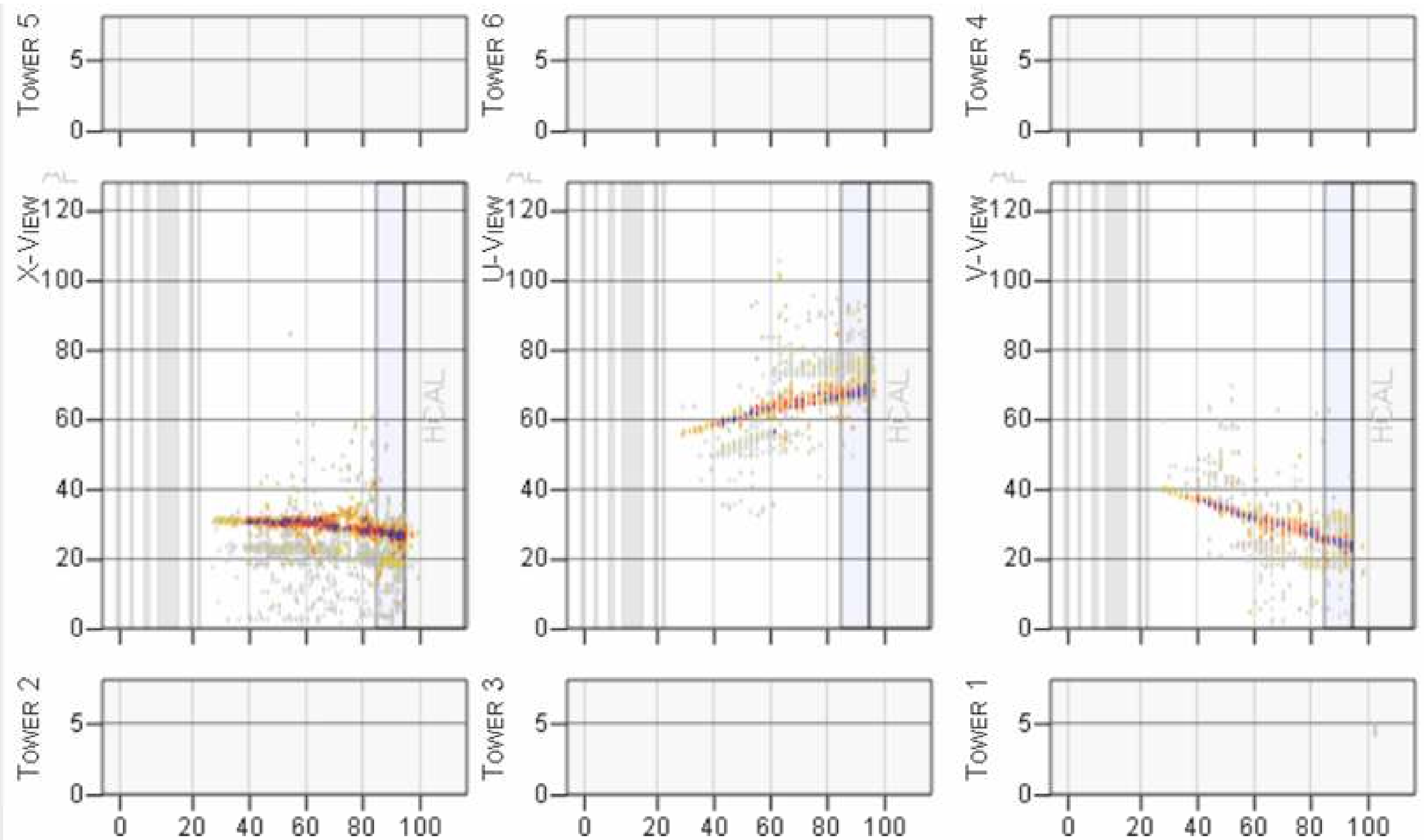
ν_e CCQE

10001|81|634



ν_e CCQE

10002|71|1672



ν_e CCQE

10001|186|1655